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FIELD TEMPERATURE MEASUREMENT IN THUNDER BAY HARBOUR (WINTER 1983)

TP 4517E

June 1983

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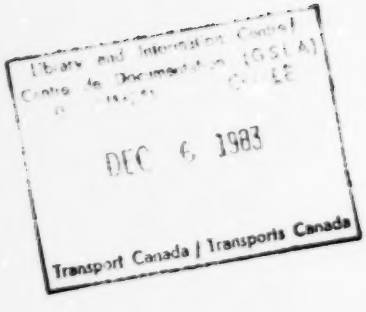

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17. Abstract

This project is one of a series of programs funded by the Transportation Development Centre of Transport Canada to develop practical ice management solutions to guarantee the early opening of the shipping season in Thunder Bay Harbour.

This project was carried out to determine the thermal budget of three port slips in the harbour by measuring water temperatures. In operation at the first slip was a two-line bubbler system, and at the second, a one-line bubbler system. The third slip had no bubbler system. The field temperature measurements were made between March 21st and 24th, 1983.

The results of this study showed a negligible water temperature gradient of 0.03° C/m under the ice cover in the slip where no bubbler system was in operation. In the presence of an operational bubbler system, the temperature was much colder and the water temperature gradient was also negligible. Recommendations for further work are also made.

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17. Résumé

Ce projet constitue un parmi plusieurs projets subventionnés par Transports Canada, Centre de développement des transports pour développer des méthodes pratiques pour aider aux opérations de déglaçage au port de Thunder Bay pour se préparer à l'ouverture de la voie maritime du fleuve St. Laurent.

Ce projet a été effectué pour déterminer le budget thermique à trois endroits différentes au port de Thunder Bay, en mesurant la température sous le couvert de glace. Un système de bulles d'air a été en fonction dans deux des trois endroits mesurés. La campagne de mesure à été effectuée entre le 21 et le 24 mars, 1983. Les résultats de cette étude ont démontré que la variation de température sous un couvert de glace est négligeable, quoique la température moyenne était plus froide en présence d'un système de bulles d'air.

Dans ce rapport, les résultats, discussions, conclusions et recommandations sont présentés.

18. Mots-clés	19. Diffusion
Température, système de bulles d'air, déglaçage, état des glaces, port de Thunder Bay	Un nombre limité d'exemplaires sont disponible au CDT

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1. INTRODUCTION

1.1 Overview

The continued effort by Transport Canada to advance the opening of Canadian harbours has brought forth several studies conducted in Thunder Bay Harbour in recent years. Among these projects was the installation of a bubbler system and subsequent monitoring of its performance over a one month period before the planned opening of the Harbour shipping season, reported by Hill [1] and Kamo et al [2].

Bubbler systems have long been used by engineers to maintain ice-free passages in northern-situated ports around the world. Based on past experience, the success of the performance of a bubbler system is due to a supply of warm water of at least 0.2°C above freezing (Ashton [3]), a condition, that is usually satisfied for Lake Superior and Thunder Bay Harbour.

Water temperature under an ice cover in lakes varies between 0 and 4°C. Under a relatively calm cooling and freeze-up condition, the water at the bottom remains at 4°C since the density of the water reaches a maximum at 4°C while the ice starts to grow on the surface, as reported by Dorsey [4] and detailed in Figure 1.1. In a relatively more turbulent condition due to ship movement in and out of the harbour, or due to wind mixing of the water, the temperature may reach as low as 0°C before freeze-up. Stewart [5] reported temperatures in the order of 0.1 to 0.2°C above freezing at depths in Lake Erie before an ice cover was formed.

As soon as an ice cover is formed over a large area, it acts as a very effective seal and temperature under the ice should remain constant until the ice starts to melt. Of course, this is assuming that no heated affluence of underground water is flowing into the area.

Ice control studies in Finnish harbours and the Saimaa Canal were carried out and reported by Eranti et al [6] and [7]. Temperatures in the order of 0.2 to 0.3° were observed to cause sufficient ice melting (sea water freezing temperature is about 1.8°C below zero) in the harbour. In the Saimaa Canal, the water temperature was usually less than 0.2°C (fresh water) in winter months. During late winter, the temperature was 0°C and no melting was observed despite extensive bubbling. However, with a temperature of + 0.6°C, bubbling showed significant melting during 115 hours of operation, when 1 m diameter of the 1 m thick ice above each orifice of the bubbler line melted. Water temperature was measured after this period and found to be + 0.2°C or a reduction of 0.4°C.

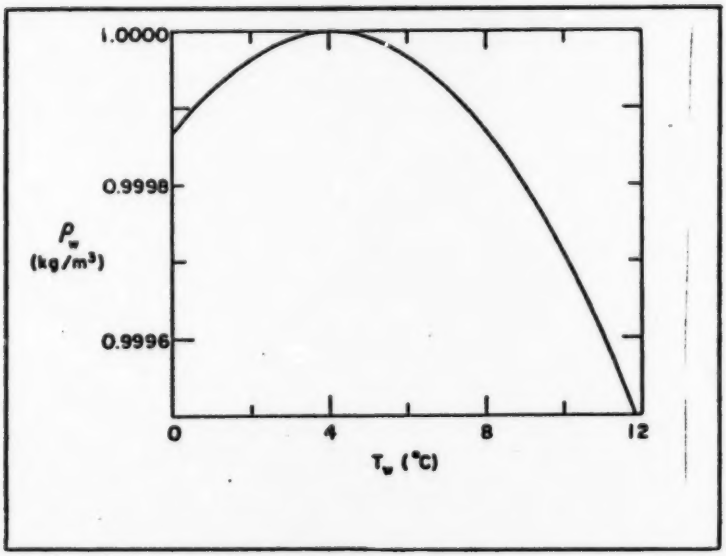
1.2 Objectives

The overall objective of this study was to extend the shipping season by controlling ice in ports and harbours.

The project objective was to carry out a water temperature survey analysis of two port slips at Thunder Bay Harbour; one actively bubbled using two bubbler lines to melt the ice and one undisturbed. An additional port slip was also considered, where a one line bubbler system installed a year earlier was in operation but not functional for a period of three days before the start of this survey.

FIGURE 1.1

EFFECT OF TEMPERATURE ON FRESH WATER DENSITY
DORSEY [4]



2. FIELD TEMPERATURE MEASUREMENT

2.1 Survey Location

The survey was conducted in Thunder Bay Harbour at three port slips as shown in Figure 2.1. The port slips were selected to provide comparative results between a slip with and without a bubbler system, and also to determine the effect of the bubbling capacity on the water temperature variation.

Slip port number one, located south of Saskatchewan pool 7A, includes one bubbler line along the wharf and extends offshore a total length of 311 meters. One compressor with a capacity of 300 m^3/hr was used. Slip port number two is located between United Grain Growers and Manitoba pool. A bubbler system was installed adjacent to both wharfs. The length of the line along the United Grain Growers wharf was 570 m, and the length of the one along the Manitoba pool wharf was 531 m. Two compressors with a capacity of 300 m^3/hr each were used for bubbling. In addition to this line bubbler system, a movable bubbling system was used but proved to be unsuccessful, according to Kano [8]. Slip port number three is located south of Cargill. This port slip was selected for comparative purposes as no bubbler system was installed there.

An overview of the winter climate, snowfall, ice thickness, temperatures, wind and other relevant information relative to Thunder Bay Harbour was described by Abdelnour in an earlier report [9].

2.2 Field Survey Procedures

Water temperature measurements were made each day at various locations in each of the three slips for a period of four days as shown in Figure 2.2. and Table 2.1. Each temperature profile made, consisted of recorded water temperatures under the ice at I m intervals, until the bottom of the slip was reached. Temperature data was acquired while lowering and retrieving the thermometer for better accuracy of the results. The temperature measurement was made using a battery—powered guildline thermometer that gave an accuracy of better than 0.05°C. Appendix B includes the operation characteristics and limitations of this thermometer. The thermometer probe was modified in-house to minimize the risk of damage. It was loaded with the necessary ballast weight to overcome its buoyancy and reach the bottom of the slips.

FIGURE 2.1 PORT SLIPS

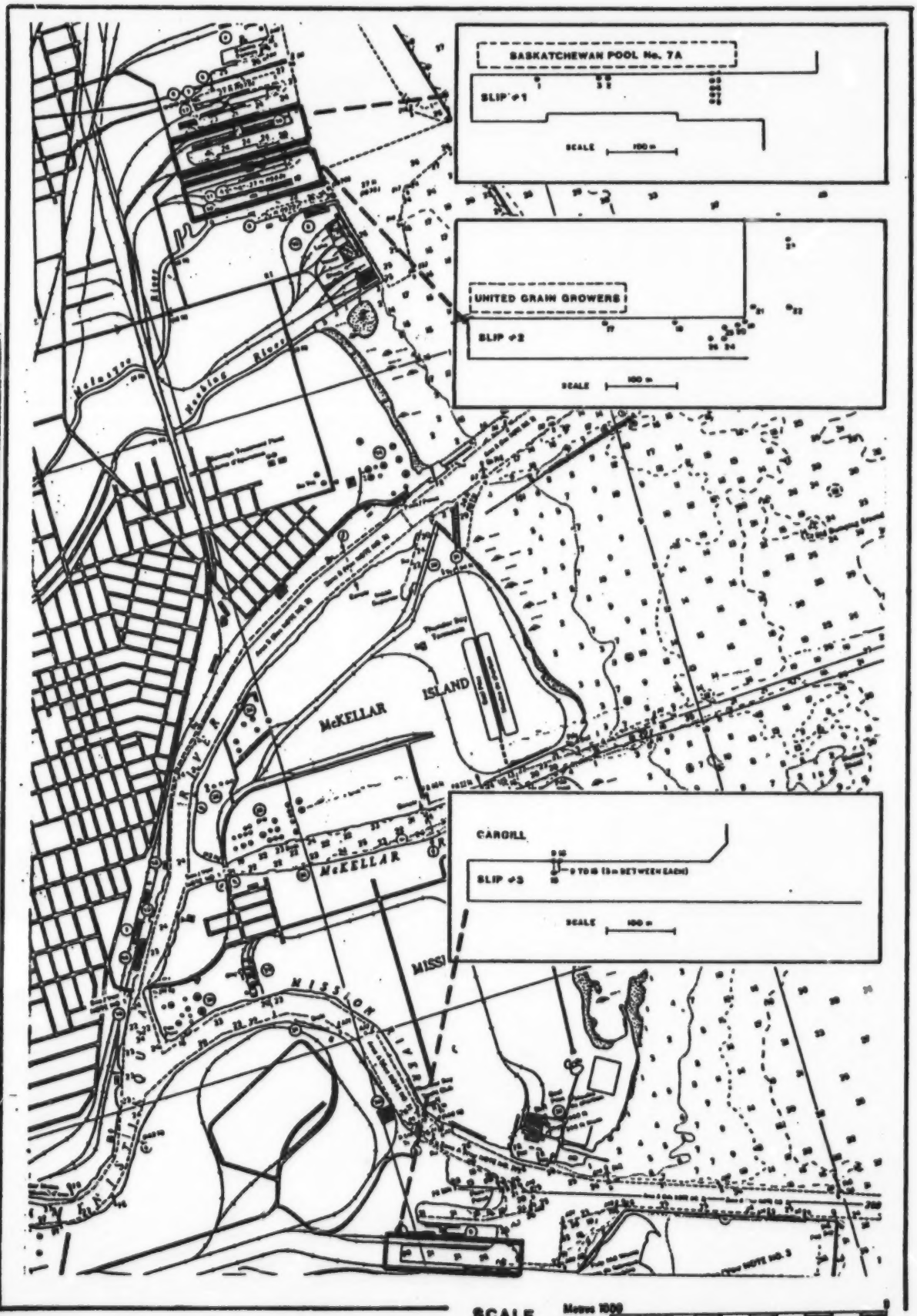
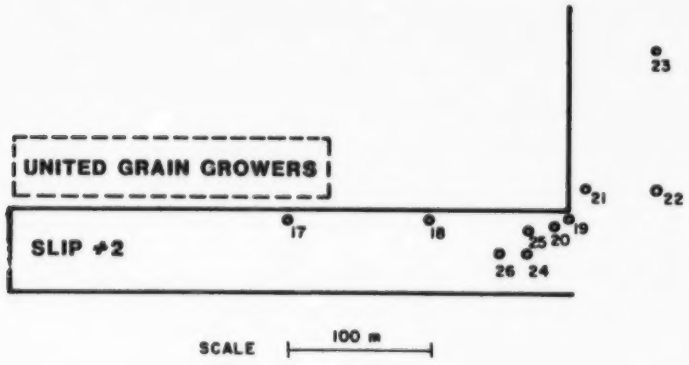
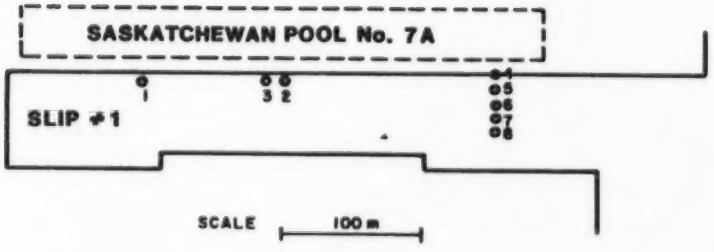


FIGURE 2.2

TEMPERATURE PROFILE LOCATIONS IN THE TESTED SLIPS





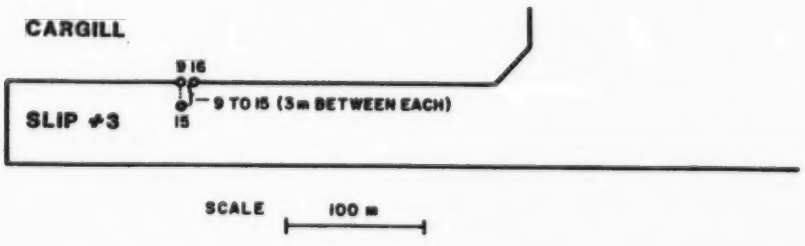


TABLE 2.1

NUMBER OF PROFILES MEASURED
AT EACH PORT SLIP

MARCH 1983	SLIP 1	SLIP 2	SLIP 3
Monday, 21	8		8
Tuesday, 22	8	10	6
Wednesday, 23	8	10	8
Thursday, 24	8	10	8
Comments	Bubbler System was installed but was not operational on Monday morning the 21st. The compressor started at noon after the temperature measurement was completed. From the 22nd to 24th the bubbler was "on". Capacity of the bubbler was 300 m^3/hr and was distributed through one line.	Bubbler system was "on" during the survey. Bubbler was in operation for a period of a month using a bubbler system of 600 m^3/hr capacity distributed through two lines along the sides of the wharfs.	No Bubbler system.

2.3 Results and Discussions

The measured temperature data is summarized in Appendix C. Table 2.2 presents the average temperature measured at each location for all 26 profiles for the period between March 21st and 24th.

The outcome of this survey provided sufficient data to investigate the following:

(1) water temperature gradient under ice;

(2) temperature variation between various points in the slip;

(3) and the effect of bubbling on water temperature.

2.3.1 Temperature Gradient:

The temperature measured at the three port slips was uniform in general and did not exhibit strong temperature gradients at various depths as shown in Figure 2.3.

The water temperature measured in slip port #1 and #2 was very uniform at all depths. In these port slips, the bubbler system was operational for a period of four weeks when significant mixing obviously occurred.

A slight water temperature gradient of about 0.03°C/m over the total depth of 6 m was measured in slip #3 (Cargill). This slip had no bubbler system in operation, and there was no significant heat discharged into the slip. However, the temperature of the water increased by 0.4°C over a 24 hour period between March 21st and 22nd. The cause of this temperature increase remains unknown. The temperature remained constant between March 22nd and 24th after the increase.

2.3.2 Average Temperature Variation in the Slip:

The locations where measurements were made in slip #2 were sufficient to establish the effect of the slip geometry on the thermal regime with the bubbling system in operation. A temperature gradient was determined between profile #17 located in the center of the slips, and at the entrance of the slip between profile #19 and #25 (see Figure 2.4). The water in the center of the slip was cooled down to 0.1°C and the water in the slip entrance was 0.25°C due to the open area where access to warmer water was relatively easier.

TABLE 2.2

SUMMARY OF AVERAGE TEMPERATURES

SLIP #	PROFILE #	AVERAGE TEMPERATURE			
		MAR 21	MAR 22	MAR 23	MAR 24
1	1	0.39	0.38	0.37	0.41
	2	0.33	0.36	0.39	0.42
	3	0.33	0.36	0.38	0.41
	4	0.35	0.34	0.34	0.38
	5	0.39	0.36	0.37	0.41
	6	0.38	0.39	0.38	0.42
	7	0.48	0.36	0.40	0.46
	8	0.54	-	0.58	0.59
3	9	0.73	-	1.11	1.12
	10	0.70	1.02	1.08	1.08
	11	0.72	1.02	1.11	1.12
	12	0.72	1.03	1.09	1.11
	13	0.76	1.03	1.12	1.17
	14	0.75	1.02	1.09	1.15
	15	0.72	1.01	1.08	1.15
	16	0.72	-	1.10	1.11
2	17	-	0.10	0.14	0.13
	18	-	0.22	0.21	0.20
	19	-	0.25	0.34	0.36
	20	-	0.26	0.34	0.35
	21	-	0.26	0.31	0.30
	22	-	0.25	0.30	0.31
	23	-	0.27	0.29	0.35
	24	-	0.28	0.31	0.27
	25	-	-	0.29	0.28
	26	-	-	0.23	0.26

FIGURE 2.3

WATER TEMPERATURE UNDER ICE COVER

21st to 24th MARCH, 1983

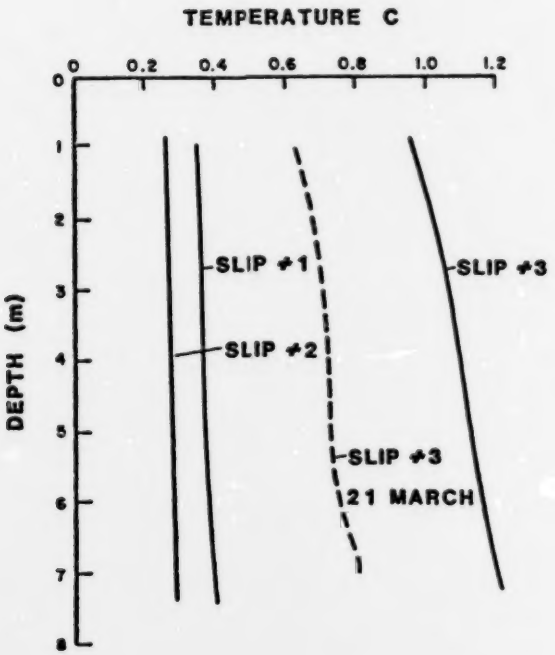
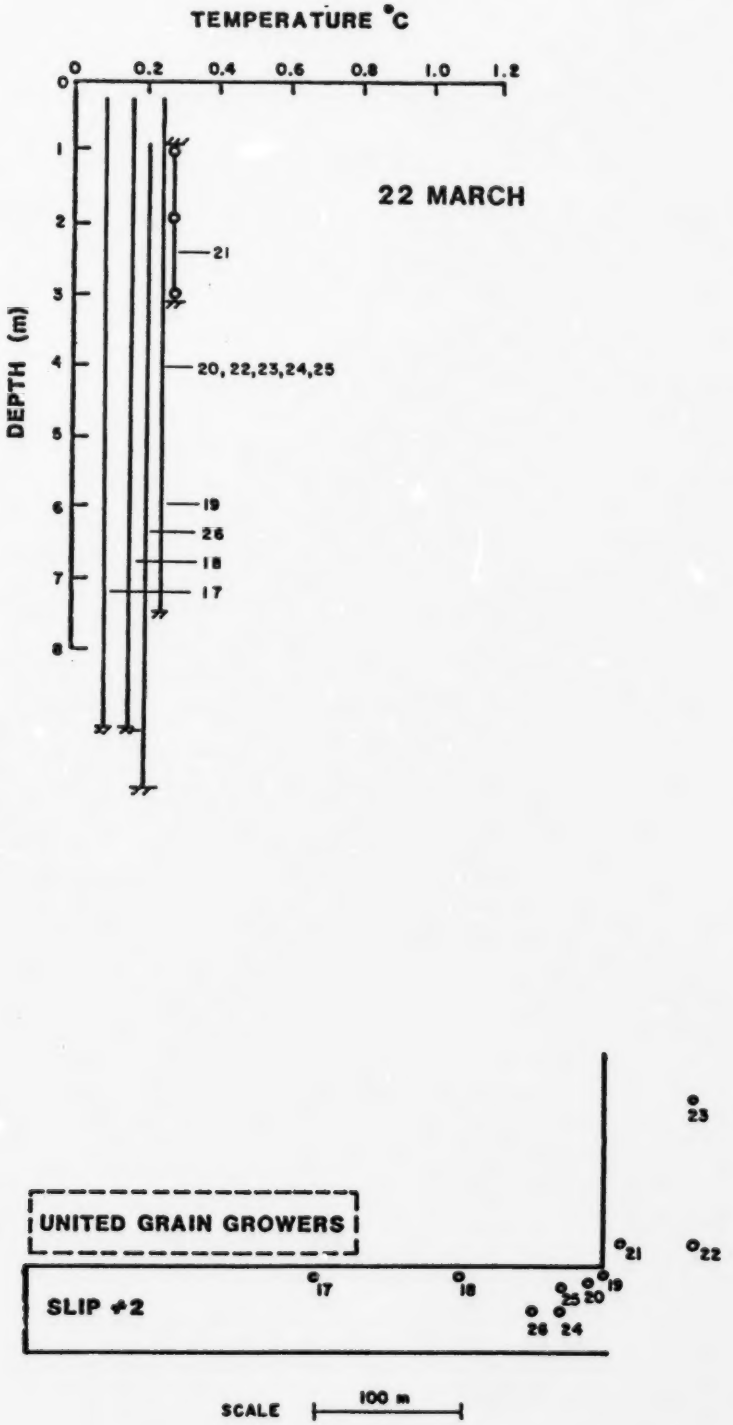


FIGURE 2.4

EFFECT OF LOCATION IN THE SLIP



2.3.3 Effect of Bubbling on Water Temperature:

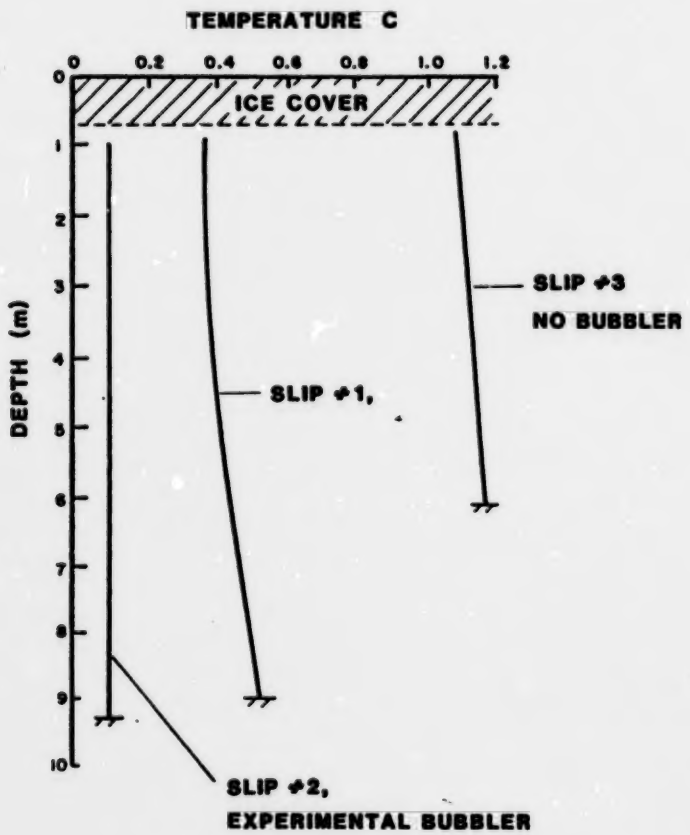
Based on the limited data obtained, bubbling showed a significant effect on reducing the water temperature inside the slip.

As shown in Figure 2.5, it appears that the two slips with the bubbler system in operation had colder temperatures than the one without a bubbler system. It is also of interest to note that the more extensive bubbler system used in slip #2 reduced the temperature to 0.1°C as compared to the less extensive one used in slip #1 which lowered the temperature to 0.33°C. The original temperature before bubbling was not measured in these two slips but could be considered with some reservations equal to the temperature measured at Cargill slip #3. However the Cargill slip is less exposed than slip #1 and #2; therefore, before the formation of an ice cover in slip #1 and #2 more mixing due to wind could be expected, and thus a lower average water temperature would result.

FIGURE 2.5

BUBBLER EFFECT ON TEMPERATURE

MARCH 24, 1983



2.4 Thermal Budget

The relatively warm water temperature measured in the slips and the harbour produces an adequate thermal reserve to provide the necessary heat to melt part of the ice cover as long as care is taken during bubbling.

The heat transferred by convection due to the currents generated by the bubbler system to melt the ice is effective as long as the water temperature is at least 0.2°C above freezing.

Therefore, the thermal budget, based on a temperature of 1°C before bubbling and a minimum low temperature of 0.2°C, for a slip that is 400 m long, 60 m wide and 8 m deep, can be calculated at approximately 154 x 10^9 calories.

This heat is capable of melting 80 mm of the ice thickness. Assuming the ice is 0.75 m thick and no heat is lost or gained during bubbling from any other source, 10.7% of the ice volume will be melted. This is a conservative estimate, since more heat is available outside the slip which has been proven by previous air bubbler experiments mentioned earlier. However, it should be noted as well, that heat losses may occur without resulting in any ice melting. This occurs if the air temperature drops below freezing and open water is maintained by continuous bubbling. This is very likely to occur in the Thunder Bay Harbour according to past records where the average temperature measured for the months of March as shown in Figure 2.6 is about -5°C (the temperature measured during the four day survey was between -14 and -5°C).

The heat losses from the open water surface resulting from air bubbling of the ice cover is significantly large in the presence of low temperatures. Based on Maykut [10], and Bengtsson [11], heat losses reach about 300 w/m² at 15°C as shown in Figure 2.7. Therefore to minimize heat losses bubbling should be interrupted at air temperatures below 0°C and resumed only when the temperature is above 0°C. As an example, an open water surface of 5% of the slip combined with an air temperature of -15°C will result in heat losses in the order of 8 x 10^9 calories/day; that is 5% of the total thermal budget of the slip. On the other hand, in the presence of warm temperatures above 0°C, heat gain will result. This has been observed by Hill [1] and Kamo et al [2] in Thunder Bay Harbour.

FIGURE 2.6

MEAN TEMPERATURES - THUNDER BAY, ONTARIO
BASED ON 30 YEARS RECORD (1941 to 1971)

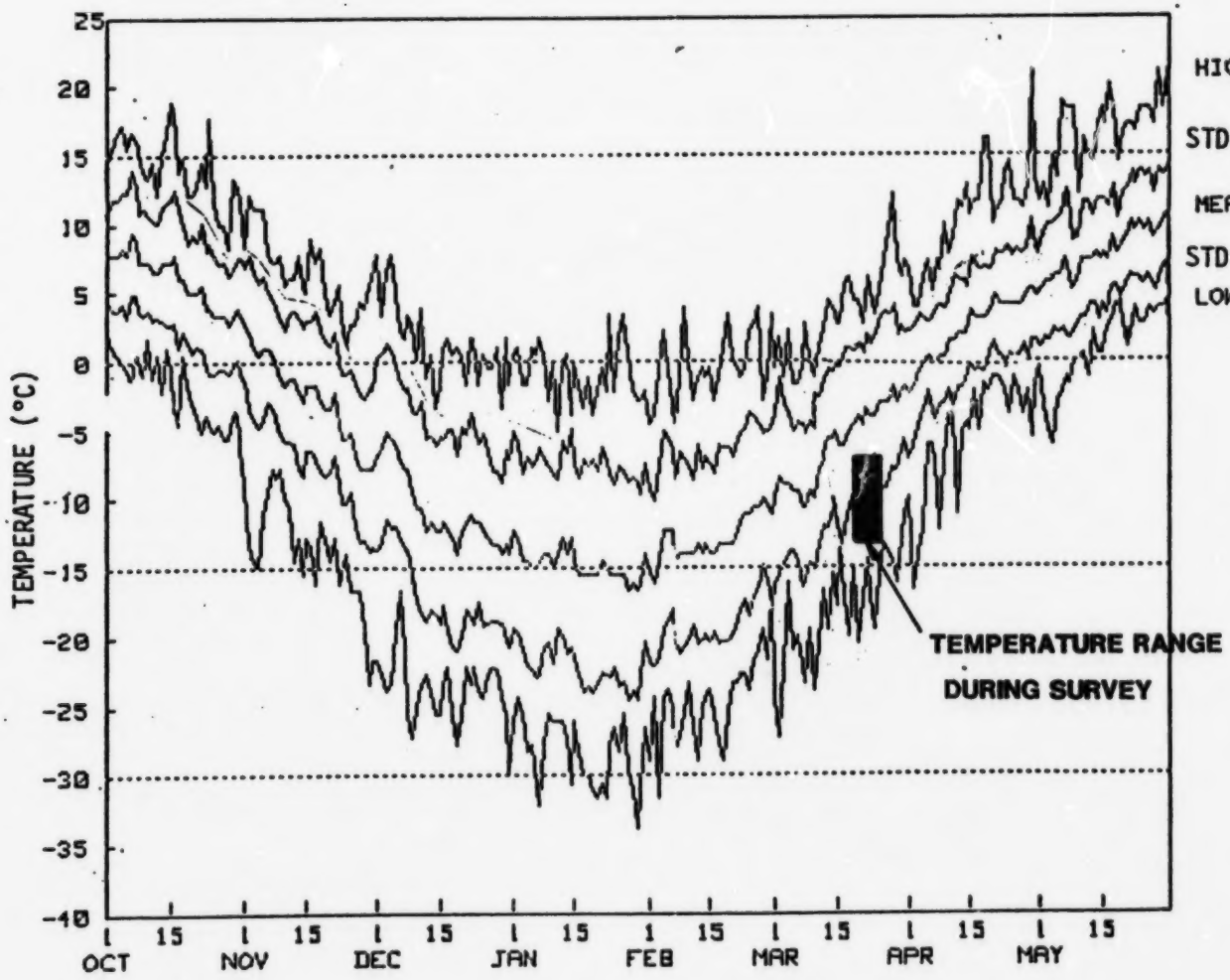
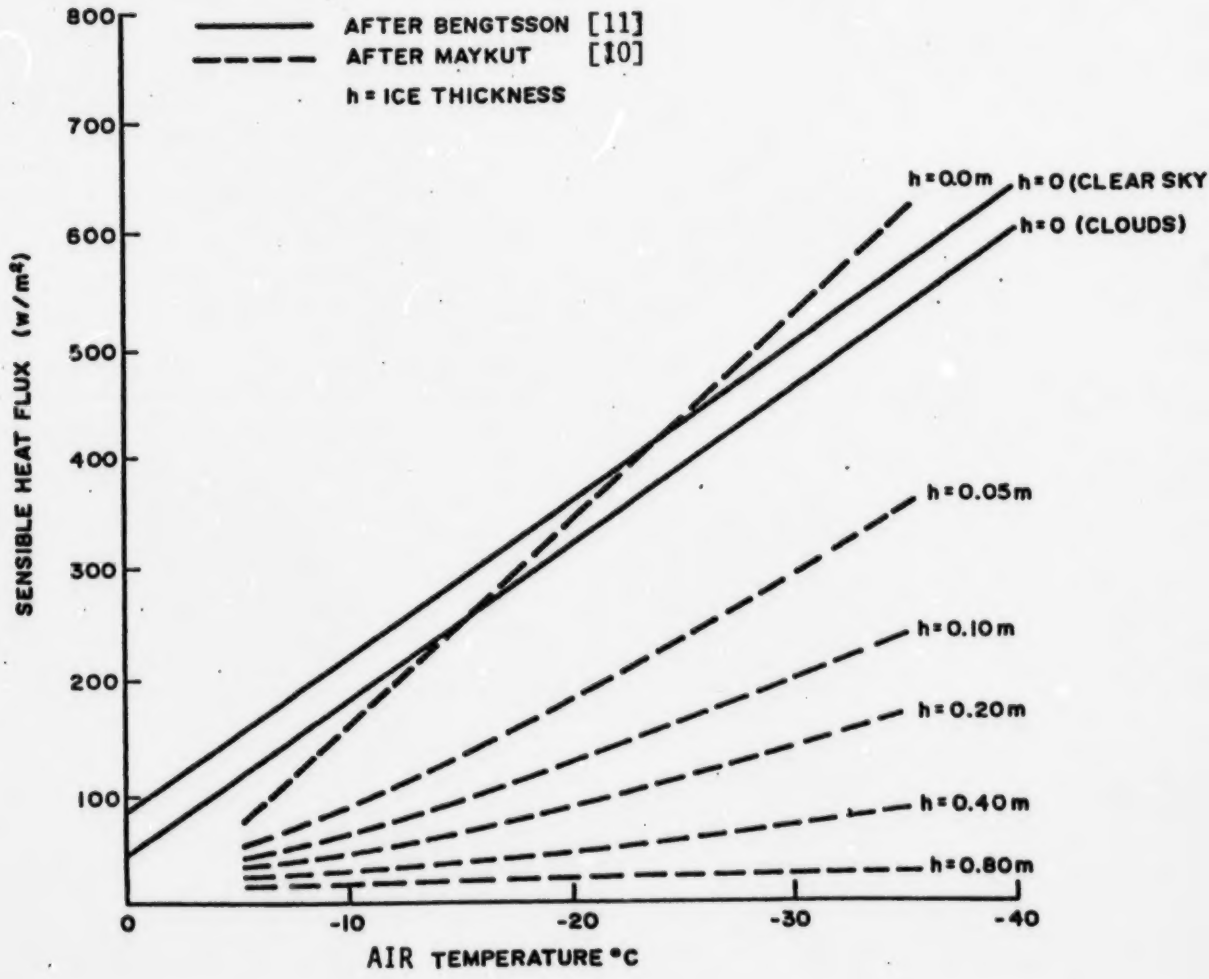


FIGURE 2.7

HEAT LOSSES FROM OPEN WATER AND AN ICE COVER SURFACE



3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

Based on the results of this survey, the following conclusions can be made:

- The gradient of the temperature profile in an undisturbed slip was less than 0.03°C/m over the 6 m depth. The temperature was almost equal at the same water depths, of all profile locations considered in the slip. This temperature gradient is negligible and the water temperature can be considered uniform with an average of 1°C.

- The operation of the bubbler system, depending on its capacity, and based on the limited data collected, showed a significant overall water temperature decrease. A water temperature as low as 0.1°C was measured in the center of the slip, while in the slip entrance, higher water temperatures in the order of 0.3°C were measured due to its closeness to the larger water mass of the harbour.

- The water temperature measured during the four-day period remained constant except for the data collected on the 21st of March at Cargill where the temperature was 0.4°C less than the following day. A ground water inflow during the night of the 21st of March may have caused this increase in temperature.

- The thermal budget available in a slip is capable of melting ten percent of the total volume of ice usually grown on the water surface. This is of course assuming that no heat is lost or gained during bubbling from any other source. Heat losses can be very significant if the bubbler maintains open water and remains in operation at very low temperatures. On the other hand, appreciable heat is gained in warm weather.

3.2 Recommendations

- Thermal budget of the harbour should be evaluated just after freeze-up.

- Continuous monitoring of the temperature distribution in one slip where a bubbler system is in operation is desirable in order to understand the thermal regime.

- The bubbler system should be designed in a way to minimize heat losses and melt the maximum possible volume of ice with the minimum available thermal budget.

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APPENDIX A

TABULATED RESULTS

TABLE 1 - SLIP # 1 (7A)

DATE	LEVEL (M)	DOWN #1	UP	AVERA	DOWN #2	UP	AVERA	DOWN #3	UP	AVERA	DOWN #4	UP	AVERA	DOWN #5	UP	AVERA	DOWN #6	UP	AVERA	DOWN #7	UP	AVERA	DOWN #8	UP	AVERA
21	1	0.26	0.26	0.26	0.26	0.27	0.27	0.05	0.26	0.15	0.11	0.29	0.20	0.26	0.30	0.28	0.25	0.28	0.27	0.31	0.32	0.31	0.31	0.33	0.32
	2	0.27	0.30	0.28	0.26	0.28	0.27	0.05	0.31	0.18	0.27	0.29	0.28	0.31	0.31	0.31	0.31	0.32	0.31	0.32	0.32	0.32	0.32	0.33	0.32
	3	0.31	0.35	0.33	0.28	0.30	0.29	0.07	0.35	0.21	0.27	0.30	0.29	0.31	0.32	0.31	0.32	0.33	0.32	0.32	0.34	0.33	0.32	0.34	0.33
	4	0.34	0.37	0.36	0.29	0.33	0.31	0.27	0.36	0.31	0.28	0.32	0.30	0.33	0.34	0.33	0.33	0.35	0.34	0.33	0.35	0.34	0.32	0.35	0.34
	5	0.37	0.39	0.38	0.30	0.36	0.33	0.36	0.39	0.38	0.32	0.36	0.34	0.35	0.37	0.36	0.34	0.38	0.36	0.35	0.38	0.36	0.35	0.39	0.37
	6	0.39	0.42	0.40	0.35	0.37	0.36	0.39	0.40	0.40	0.34	0.40	0.37	0.38	0.41	0.40	0.38	0.40	0.39	0.38	0.40	0.39	0.39	0.41	0.40
	7	0.43	0.44	0.43	0.37	0.39	0.38	0.43	0.44	0.44	0.38	0.44	0.41	0.42	0.45	0.43	0.42	0.45	0.44	0.42	0.44	0.43	0.42	0.44	0.43
	8	0.46	0.50	0.48	0.40		0.40	0.45	0.45	0.45	0.43	0.47	0.45	0.42	0.47	0.44	0.45	0.47	0.46	0.45	0.50	0.47	0.45	0.49	0.47
	9	0.56		0.56				0.47		0.47	0.53		0.53	0.45		0.45	0.55		0.55	0.55	0.57	0.56	0.53	0.70	0.61
	10													0.48		0.48				1.30		1.30	1.77		1.77
	11													0.54		0.54									
				0.39			0.33			0.33			0.35			0.39			0.38			0.48			0.54
22	1	0.37	0.38	0.37	0.36	0.35	0.36	0.37	0.36	0.36	0.32	0.34	0.33	0.34	0.34	0.34	0.32	0.34	0.33	0.33	0.34	0.33			
	2	0.38	0.38	0.38	0.36	0.36	0.36	0.36	0.36	0.36	0.32	0.34	0.33	0.34	0.35	0.34	0.33	0.34	0.34	0.33	0.34	0.33			
	3	0.37	0.37	0.37	0.36	0.36	0.36	0.36	0.36	0.36	0.33	0.35	0.34	0.34	0.35	0.34	0.34	0.35	0.34	0.34	0.34	0.34			
	4	0.37	0.37	0.37	0.35	0.36	0.36	0.36	0.36	0.36	0.33	0.35	0.34	0.34	0.35	0.35	0.34	0.35	0.35	0.34	0.35	0.35			
	5	0.37	0.37	0.37	0.36	0.36	0.36	0.36	0.36	0.36	0.34	0.36	0.35	0.35	0.36	0.35	0.35	0.36	0.36	0.35	0.36	0.35			
	6	0.38	0.38	0.38	0.36	0.36	0.36	0.36	0.36	0.36	0.34	0.37	0.35	0.35	0.36	0.36	0.35	0.36	0.36	0.35	0.37	0.36			
	7	0.38	0.39	0.38	0.36	0.36	0.36	0.36	0.37	0.36	0.36	0.37	0.36	0.37	0.38	0.37	0.36	0.37	0.37	0.37	0.38	0.38			
	8	0.39		0.39	0.36		0.36	0.37		0.37	0.38	0.40	0.39	0.40	0.41	0.40	0.38	0.42	0.40	0.40	0.42	0.41			
	9										0.30		0.30	0.42		0.42	0.41	0.46	0.43	0.42		0.42			
	10																0.65		0.65						
				0.38			0.36			0.36			0.34			0.36			0.39			0.36			
23	1	0.36	0.37	0.36	0.37	0.38	0.37	0.38	0.38	0.38	0.08	0.35	0.21	0.34	0.35	0.35	0.35	0.35	0.35	0.32	0.35	0.34	0.35	0.35	0.35
	2	0.38	0.37	0.37	0.38	0.38	0.38	0.38	0.38	0.38	0.19	0.35	0.27	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.36	0.35	0.35	0.36	0.36
	3	0.36	0.37	0.37	0.37	0.38	0.38	0.38	0.38	0.38	0.26	0.35	0.30	0.35	0.35	0.35	0.35	0.36	0.35	0.35	0.37	0.36	0.36	0.36	0.36
	4	0.37	0.37	0.37	0.38	0.38	0.38	0.38	0.38	0.38	0.34	0.35	0.34	0.34	0.35	0.34	0.35	0.36	0.35	0.35	0.37	0.36	0.36	0.37	0.37
	5	0.37	0.37	0.37	0.38	0.38	0.38	0.38	0.38	0.38	0.32	0.35	0.34	0.35	0.35	0.35	0.35	0.37	0.36	0.36	0.38	0.37	0.37	0.38	0.37
	6	0.37	0.37	0.37	0.38	0.38	0.38	0.38	0.38	0.38	0.33	0.36	0.35	0.35	0.37	0.36	0.37	0.37	0.37	0.37	0.38	0.37	0.37	0.41	0.39
	7	0.37	0.37	0.37	0.38	0.39	0.38	0.38	0.38	0.38	0.33	0.41	0.37	0.36	0.38	0.37	0.36	0.38	0.37	0.37	0.38	0.38	0.37	0.46	0.42
	8	0.38		0.38	0.48		0.48		0.38	0.38	0.54		0.54	0.38	0.40	0.39	0.41	0.46	0.43	0.39	0.44	0.42	0.43	0.57	0.50
	9								0.38	0.38				0.48		0.48	0.50		0.50	0.46	0.48	0.47	0.48		0.48
	10																			0.57		0.57	2.24		2.24
				0.37			0.39			0.38			0.34			0.37			0.38			0.40			0.58
24	1	0.41	0.41	0.41	0.42	0.42	0.42	0.40	0.41	0.41	0.37	0.37	0.37	0.38	0.38	0.38	0.38	0.37	0.37	0.37	0.38	0.37	0.38	0.39	0.38
	2	0.41	0.41	0.41	0.42	0.42	0.42	0.41	0.41	0.41	0.36	0.39	0.37	0.39	0.39	0.39	0.37	0.38	0.37	0.38	0.38	0.38	0.38	0.39	0.39
	3	0.41	0.41	0.41	0.42	0.42	0.42	0.41	0.41	0.41	0.35	0.39	0.37	0.39	0.41	0.40	0.38	0.38	0.38	0.38	0.39	0.38	0.38	0.39	0.39
	4	0.41	0.41	0.41	0.42	0.42	0.42	0.42	0.41	0.42	0.36	0.39	0.38	0.39	0.42	0.40	0.38	0.39	0.38	0.38	0.39	0.39	0.40	0.39	0.39
	5	0.41	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.38	0.39	0.38	0.39	0.43	0.41	0.38	0.41	0.40	0.38	0.41	0.40	0.40	0.42	0.41
	6	0.41	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.37	0.39	0.38	0.40	0.45	0.42	0.40	0.44	0.42	0.39	0.50	0.45	0.41	0.44	0.43
	7	0.41	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.37	0.38	0.38		0.49	0.49	0.44	0.47	0.45	0.43	0.51	0.47	0.44	0.47	0.45
	8	0.43		0.43	0.42		0.42	0.42		0.42	0.39	0.40	0.40				0.47	0.50	0.49	0.49	0.52	0.51	0.45	0.51	0.48
	9										0.39		0.39				0.51		0.51	0.51	0.53	0.52	0.48	0.54	0.51
	10																			0.71		0.71	2.10		2.10
				0.41			0.42			0.41			0.38			0.41			0.42			0.46			0.59

TABLE 2 - SLIP # 2 (UNITED GRAIN GROWERS)

DATE	LEVEL (M)	DOWN #17	UP	AVERA	DOWN #18	UP	AVERA	DOWN #19	UP	AVERA	DOWN #20	UP	AVERA	DOWN #21	UP	AVERA	DOWN #22	UP	AVERA	DOWN #23	UP	AVERA	DOWN #24	UP	AVERA	DOWN #25	UP	AVERA	DOWN #26	UP	AVERA
22	1	0.10	0.11	0.10	0.14	0.17	0.15	0.25	0.25	0.25	0.26	0.26	0.26	0.25	0.26	0.26	0.25	0.26	0.25	0.27	0.28	0.27	0.17	0.29	0.23						
	2	0.10	0.11	0.10	0.14	0.17	0.15	0.24	0.25	0.25	0.26	0.26	0.26	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.27	0.26	0.20	0.30	0.25						
	3	0.10	0.11	0.10	0.14	0.16	0.15	0.24	0.25	0.24	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.26	0.26	0.26	0.20	0.30	0.25						
	4	0.10	0.10	0.10	0.15	0.16	0.15	0.24	0.25	0.24	0.26	0.26	0.26	0.27		0.27	0.25	0.24	0.25	0.25	0.26	0.26	0.29	0.29	0.29						
	5	0.10	0.10	0.10	0.16	0.16	0.16	0.24	0.25	0.24	0.26	0.26	0.26				0.25	0.25	0.25	0.32		0.32	0.29	0.29	0.29						
	6	0.10	0.10	0.10	0.16	0.16	0.16	0.24	0.24	0.24	0.26	0.26	0.26				0.26		0.26				0.28	0.29	0.29						
	7	0.10	0.10	0.10	0.16	0.16	0.16	0.25	0.25	0.25	0.26	0.26	0.26										0.28	0.28	0.28						
	8	0.11	0.11	0.11	0.17	0.16	0.17	0.25		0.25	0.26	0.26	0.26										0.29	0.29	0.29						
	9	0.11	0.11	0.11	0.17	0.17	0.17	0.26		0.26	0.26		0.26										0.29	0.29	0.29						
	10	0.10		0.10	0.76		0.76																0.29	0.29	0.29						
	11																						0.31		0.31						
				0.10			0.22			0.25			0.26			0.26			0.25			0.27			0.28						
23	1	0.14	0.14	0.14	0.22	0.21	0.22	0.35	0.35	0.35	0.34	0.34	0.34	0.29	0.31	0.30	0.24	0.31	0.28	0.11	0.33	0.22	0.26	0.28	0.27	0.27	0.30	0.28	0.22	0.23	0.23
	2	0.14	0.14	0.14	0.21	0.21	0.21	0.35	0.34	0.34	0.35	0.34	0.34	0.30	0.30	0.30	0.30	0.31	0.30	0.18	0.31	0.24	0.27	0.28	0.28	0.29	0.29	0.29	0.22	0.22	0.22
	3	0.14	0.14	0.14	0.21	0.21	0.21	0.34	0.34	0.34	0.35	0.34	0.34	0.30	0.31	0.30	0.30	0.31	0.31	0.19	0.31	0.25	0.28	0.28	0.28	0.28	0.29	0.29	0.23	0.23	0.23
	4	0.14	0.14	0.14	0.21	0.21	0.21	0.34	0.34	0.34	0.34	0.34	0.34	0.33		0.33	0.30	0.31	0.30	0.29	0.31	0.30	0.28	0.28	0.28	0.28	0.30	0.29	0.23	0.23	0.23
	5	0.14	0.14	0.14	0.21	0.21	0.21	0.34	0.34	0.34	0.34	0.34	0.34				0.30	0.31	0.30	0.45		0.45	0.28	0.28	0.28	0.28	0.29	0.28	0.23	0.23	0.23
	6	0.14	0.14	0.14	0.21	0.21	0.21	0.34	0.34	0.34	0.34	0.34	0.34				0.30		0.30				0.28	0.28	0.28	0.28	0.28	0.28	0.23	0.23	0.23
	7	0.14	0.14	0.14	0.21	0.21	0.21	0.34		0.34	0.34	0.34	0.34										0.28	0.28	0.28	0.28	0.28	0.28	0.24	0.23	0.23
	8	0.14		0.14	0.21	0.21	0.21				0.34	0.34	0.34										0.28	0.29	0.28	0.28	0.28	0.28	0.23	0.23	0.23
	9				0.21		0.21																0.32	0.38	0.35	0.28	0.28	0.28	0.23	0.23	0.23
	10																						0.40	0.43	0.42	0.31		0.31	0.23	0.23	0.23
	11																						0.45		0.45				0.30		0.30
				0.14			0.21			0.34			0.34			0.31			0.30			0.29			0.31			0.29			0.23
24	1	0.13	0.13	0.13	0.20	0.20	0.20	0.35	0.36	0.36	0.35	0.35	0.35	0.29		0.29	0.22	0.30	0.26	0.19	0.31	0.25	0.22	0.27	0.24	0.28	0.28	0.28	0.26	0.26	0.26
	2	0.13	0.13	0.13	0.20	0.20	0.20	0.36	0.36	0.36	0.35	0.35	0.35	0.30		0.30	0.28	0.31	0.30	0.29	0.32	0.31	0.25	0.28	0.27	0.28	0.28	0.28	0.26	0.26	0.26
	3	0.13	0.13	0.13	0.20	0.20	0.20	0.36	0.36	0.36	0.35	0.35	0.35	0.30		0.30	0.29	0.33	0.31	0.31	0.35	0.33	0.26	0.27	0.27	0.27	0.28	0.27	0.26	0.26	0.26
	4	0.13	0.13	0.13	0.20	0.20	0.20	0.37	0.36	0.36	0.35	0.35	0.35	0.31		0.31	0.32	0.33	0.32	0.35	0.38	0.37	0.27	0.27	0.27	0.27	0.28	0.27	0.26	0.26	0.26
	5	0.13	0.13	0.13	0.20	0.20	0.20	0.37	0.36	0.36	0.35	0.35	0.35				0.33	0.33	0.33	0.50		0.50	0.27	0.28	0.27	0.27	0.27	0.27	0.26	0.26	0.26
	6	0.13	0.13	0.13	0.20	0.20	0.20	0.37	0.36	0.36	0.35	0.35	0.35				0.36		0.36				0.27	0.28	0.27	0.27	0.27	0.27	0.27	0.26	0.26
	7	0.13	0.13	0.13	0.20	0.20	0.20	0.36	0.35	0.35	0.35	0.35	0.35										0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.26
	8	0.13	0.13	0.13	0.20	0.20	0.20	0.36		0.36	0.36	0.35	0.35										0.27	0.27	0.27	0.27	0.28	0.27	0.27	0.26	0.26
	9	0.13		0.13	0.20		0.20				0.35	0.35	0.35										0.28	0.29	0.28	0.28	0.28	0.28	0.27	0.26	0.27
	10				0.20		0.20				0.35	0.35	0.35										0.29	0.29	0.29	0.29		0.29	0.27	0.26	0.26
	11										0.35	0.35	0.35										0.31		0.31				0.27		0.27
				0.13			0.20			0.36			0.35			0.30			0.31			0.35			0.27			0.28			0.26

TABLE 3 - SLIP # 3 - CARGILL

DATE	LEVEL (M)	DOWN #16	UP	AVERA	DOWN #15	UP	AVERA	DOWN #14	UP	AVERA	DOWN #13	UP	AVERA	DOWN #12	UP	AVERA	DOWN #11	UP	AVERA	DOWN #10	UP	AVERA	DOWN #9	UP	AVERA
21	1	0.41	0.66	0.53	0.65	0.67	0.66	0.67	0.69	0.68	0.63	0.70	0.66	0.64	0.67	0.65	0.60	0.65	0.62	0.49	0.66	0.58	0.58	0.66	0.62
	2	0.61	0.68	0.65	0.67	0.69	0.68	0.68	0.69	0.69	0.69	0.70	0.69	0.67	0.69	0.68	0.66	0.69	0.67	0.65	0.68	0.67	0.62	0.69	0.66
	3	0.66	0.70	0.68	0.67	0.70	0.68	0.68	0.70	0.69	0.69	0.70	0.70	0.68	0.70	0.69	0.68	0.70	0.69	0.68	0.69	0.69	0.67	0.70	0.69
	4	0.69	0.71	0.70	0.71	0.73	0.72	0.70	0.73	0.72	0.70	0.73	0.71	0.70	0.73	0.71	0.70	0.72	0.71	0.69	0.71	0.70	0.69	0.71	0.70
	5	0.71	0.74	0.72	0.73	0.78	0.75	0.72	0.77	0.74	0.73	0.75	0.74	0.72	0.76	0.74	0.72	0.74	0.73	0.71	0.73	0.72	0.71	0.72	0.71
	6	0.73	0.75	0.74	0.78	0.83	0.80	0.78	0.79	0.78	0.77	0.79	0.78	0.75	0.79	0.77	0.76	0.78	0.77	0.74	0.79	0.76	0.72	0.72	0.72
	7	1.04		1.04	1.05			0.96		0.96	1.04		1.04	0.80	0.81	0.81	0.79	0.84	0.81	0.77	0.78	0.78	1.00		1.00
	8													1.05		1.05	1.33		1.33	1.00		1.00			
				0.72			0.72			0.75			0.76			0.72			0.72			0.70			0.73
22	1				0.89	0.91	0.90	0.93	0.93	0.93	0.92	0.95	0.93	0.96	0.96	0.96	0.85	0.91	0.88	0.88	0.95	0.92			
	2				0.90	0.93	0.92	0.92	0.95	0.93	0.95	0.95	0.95	0.97	0.98	0.98	0.93	0.97	0.95	0.96	0.98	0.97			
	3				0.96	0.98	0.97	0.95	0.98	0.97	0.94	0.99	0.97	0.97	1.00	0.99	0.98	1.01	0.99	0.98	1.02	1.00			
	4				0.97	1.02	0.99	0.97	1.10	1.04	0.99	1.04	1.02	1.00	1.04	1.02	1.03	1.05	1.04	1.02	1.03	1.02			
	5				1.04	1.03	1.03	1.02	1.06	1.04	1.03	1.09	1.06	1.03	1.08	1.06	1.04	1.06	1.05	1.04	1.05	1.04			
	6				1.08	1.10	1.09	1.09	1.12	1.11	1.08	1.11	1.10	1.08	1.10	1.09	1.08	1.12	1.10	1.06	1.09	1.07			
	7				1.17		1.17	1.14		1.14	1.22		1.22	1.13		1.13	1.12	1.17	1.15	1.11	1.12	1.12			
	8																1.41		1.41	1.21		1.21			
							1.01			1.02			1.03			1.03			1.02			1.02			
23	1	0.93	0.95	0.94	0.91	0.37	0.94	0.96	0.99	0.98	0.96	1.00	0.98	1.03	1.01	1.02	1.01	1.02	1.01	0.92	0.98	0.95	0.92	0.96	0.94
	2	0.99	1.00	1.00	0.93	1.03	0.98	0.96	1.04	1.00	0.96	1.06	1.01	1.01	1.01	1.01	0.99	1.07	1.03	0.98	1.02	1.00	0.99	1.03	1.01
	3	1.05	1.07	1.06	0.95	1.09	1.02	1.02	1.09	1.05	1.11	1.10	1.11	1.05	1.11	1.08	1.07	1.12	1.09	1.07	1.12	1.09	1.07	1.10	1.09
	4	1.10	1.10	1.10	1.06	1.13	1.09	1.11	1.13	1.12	1.07	1.13	1.10	1.09	1.13	1.11	1.12	1.14	1.13	1.12	1.12	1.12	1.11	1.12	1.11
	5	1.11	1.14	1.12	1.10	1.14	1.12	1.12	1.14	1.13	1.12	1.14	1.13	1.12	1.14	1.13	1.14	1.15	1.14	1.13	1.14	1.13	1.11	1.12	1.12
	6	1.15	1.17	1.16	1.13	1.17	1.15	1.14	1.16	1.15	1.13	1.16	1.15	1.13	1.16	1.15	1.15	1.17	1.16	1.14	1.14	1.14	1.13	1.15	1.14
	7	1.32		1.32	1.29		1.29	1.22		1.22	1.35		1.35	1.16	1.18	1.17	1.18	1.19	1.18	1.13	1.13	1.13	1.35		1.35
	8													1.33		1.33	1.53		1.53	1.25		1.25			
				1.10			1.08			1.09			1.12			1.09			1.11			1.08			1.11
24	1	1.00	1.10	1.05	1.04	1.10	1.07	1.04	1.11	1.08	1.13	1.14	1.14	1.03	1.01	1.02	1.10	1.03	1.06	1.00	1.02	1.01	0.98	1.11	1.05
	2	1.10	1.10	1.10	1.10	1.12	1.11	1.10	1.12	1.11	1.14	1.15	1.14	1.03	1.12	1.07	1.02	1.07	1.05	1.03	1.03	1.03	1.10	1.13	1.12
	3	1.10	1.11	1.11	1.11	1.12	1.11	1.11	1.13	1.12	1.14	1.15	1.15	1.07	1.12	1.10	1.10	1.13	1.11	1.07	1.05	1.06	1.13	1.14	1.14
	4	1.11	1.12	1.11	1.12	1.14	1.13	1.12	1.13	1.13	1.14	1.16	1.15	1.12	1.15	1.13	1.12	1.14	1.13	1.10	1.07	1.09	1.13	1.14	1.14
	5	1.12	1.15	1.13	1.15	1.16	1.15	1.14	1.15	1.14	1.15	1.16	1.16	1.13	1.15	1.14	1.15	1.16	1.16	1.12	1.10	1.11	1.13	1.14	1.14
	6	1.13	1.15	1.14	1.17	1.17	1.17	1.16	1.18	1.17	1.15	1.18	1.16	1.14	1.16	1.15	1.15	1.17	1.16	1.13	1.12	1.13	1.13	1.14	1.14
	7				1.30		1.30	1.30		1.30	1.32		1.32	1.16	1.18	1.17	1.17	1.19	1.18	1.15		1.15	1.13	1.14	1.14
	8													1.36		1.36	1.62		1.62					1.15	1.15
				1.11			1.15			1.15			1.17			1.11			1.12			1.08			1.12

APPENDIX B

GUILDLINE INSTRUMENT SPECIFICATIONS

GUILDLINE INSTRUMENT SPECIFICATIONS

*GUARANTEED PERFORMANCE Including Supplied Probe

Range	23 C ± 1°C	23°C ± 5C°	
C -5 to +40	24 hours 0.01K	90 days 0.03K	1 Year 0.06K
-20 to -5 and +40 to +100	0.05K	0.06K	0.12K
-50 to -20 and +100 to +200	0.05K	0.15K	0.3K
-100 to -50	1K	2K	2K

Resolution: 0.001K between -20 to +40°C
0.01K below -20 and above+40°C

Temperature Coefficient: Less than ± 0.0005K/K

Repeatability: ± 2 least significant digits
Readout 0.5" Liquid Crystal Display
Warm up to full rated accuracy:
30 seconds
System time constant: 5 seconds

Sensor Description:

Type: 4 wire, Platinum Resistance, 100 ohm at ICE point. Sensor Current 2.5 mA.

The sensor furnished is encapsulated in a stainless steel sheath. The probe itself is 228.6 mm in length and is 3.13 mm in diameter at the tip. The immersion depth is 50.3 mm. Standard lead length is 2 m..

Self-Heating: Less than 0.015K at 23° C in flowing water at 1m / s
Thermal characteristics of Sensor:
Less than 0.02K / Milliwatt

Rechargeable Battery Pack:

An optional self-contained rechargeable battery pack will provide up to 6 hours of uninterrupted operation in an ambient of 23 C.

There is a "Low Battery" indicator in the display. A built-in storage compartment for the battery charger is provided.

* 1 K = 1 Celsius degree

*Total guaranteed performance stated is worst case. It assumes all contributing errors are maximum and occur at the same time and in the same direction. Contributing errors include calibration uncertainty which is referred to flowing water at the rate of 1 m / s, repeatability, stability, temperature coefficient, linearization plus sensor and electronics drift.

Data Systems Options:

Digital output - BCD - Parallel
Command levels are TTL, positive 5V Logic

Analog output - 50 millivolts / K

ENVIRONMENTAL SPECIFICATIONS

Storage Temperature - -20° C to + 70° C

Operating Temperature - 0° C to +50° C

Relative Humidity - ≤ 75% non-condensing, from 0 to 50° C

Power Requirements - 120V / 60Hz less than 5VA

Weight 4 lbs.

Size 11.5" wide, 3" high, 7.75" deep.
294 mm wide, 78 mm high, 198 mm deep

APPENDIX C

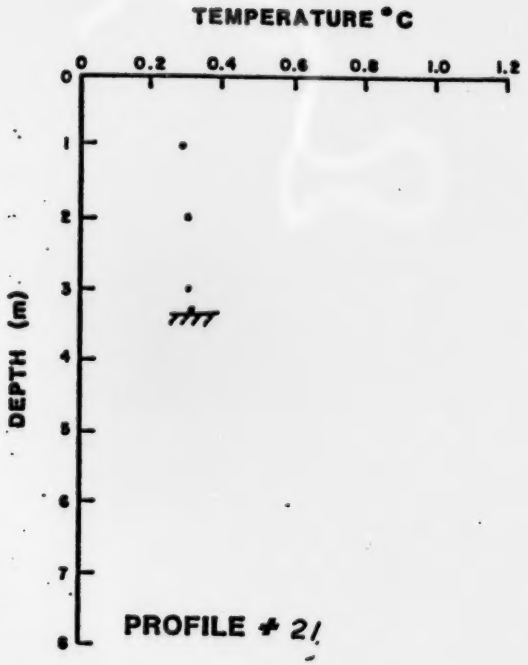
TEMPERATURE PROFILES

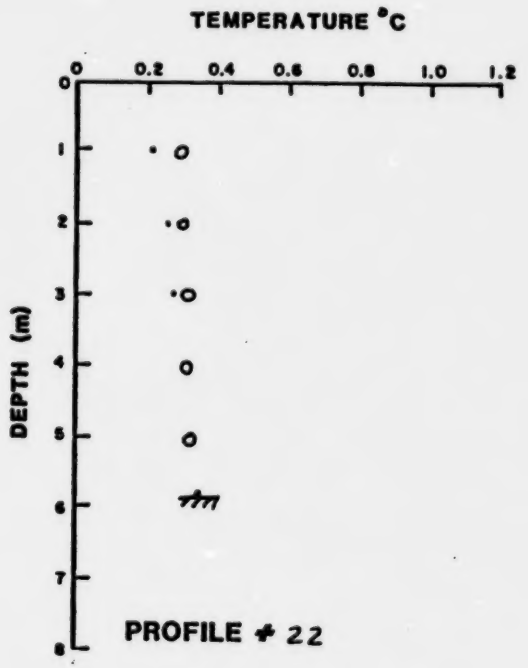
PORT SLIP: EXPERIMENTAL SLIP (BUBBLING SYSTEM)

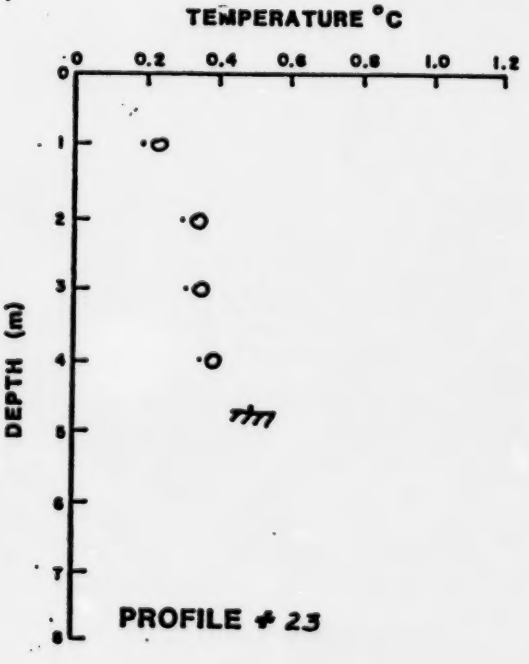
DATE : MARCH 24, 1983

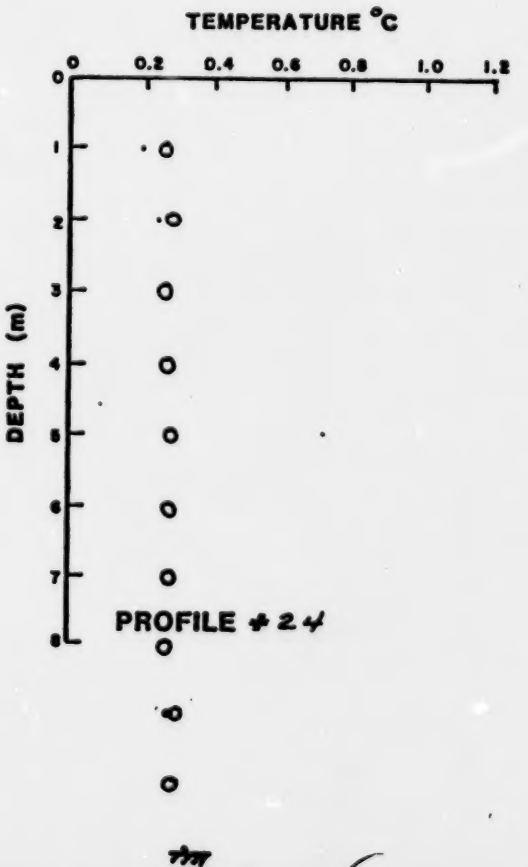
TIME :

AIR TEMP. : -11.242





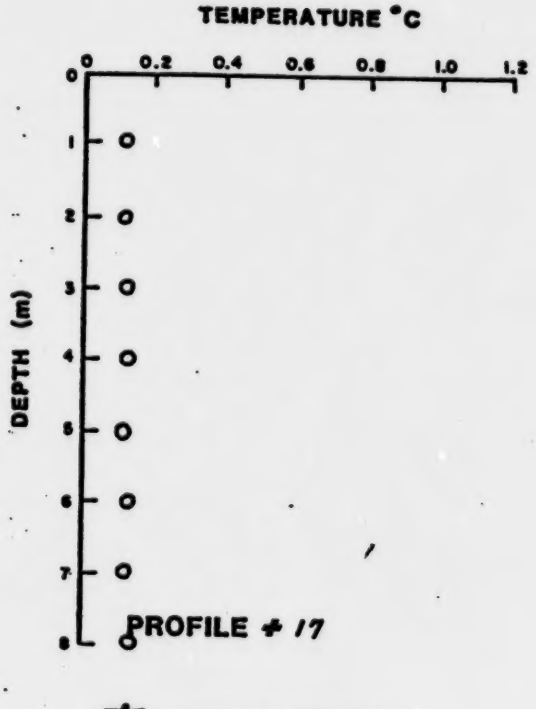


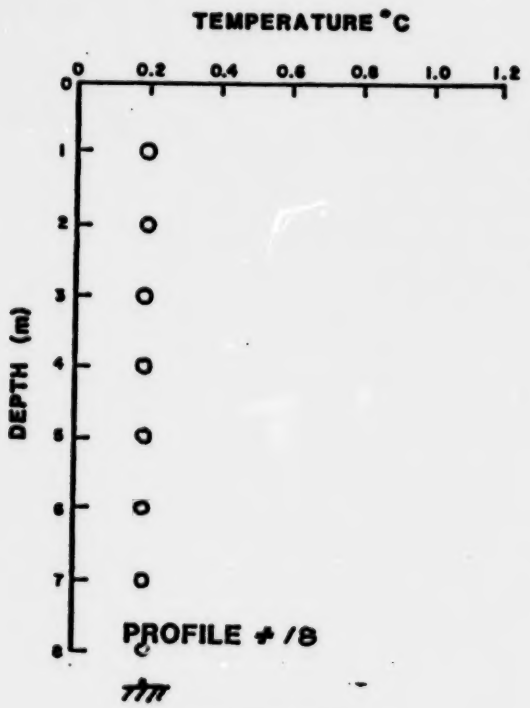


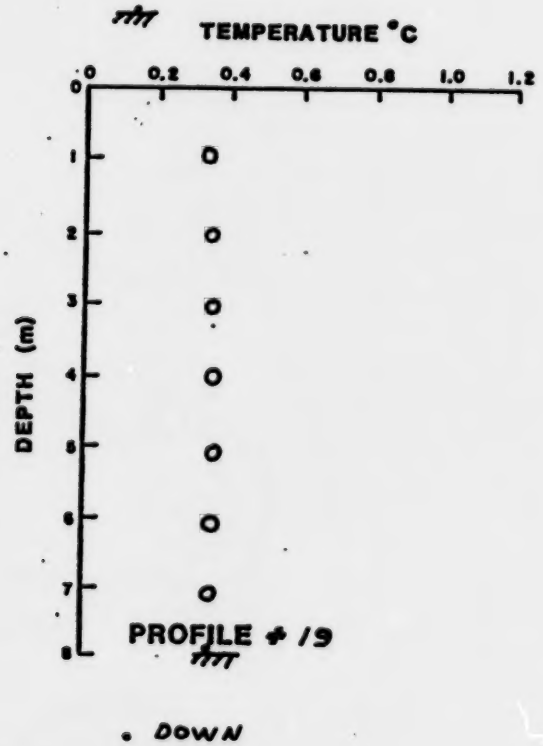
• DOWN

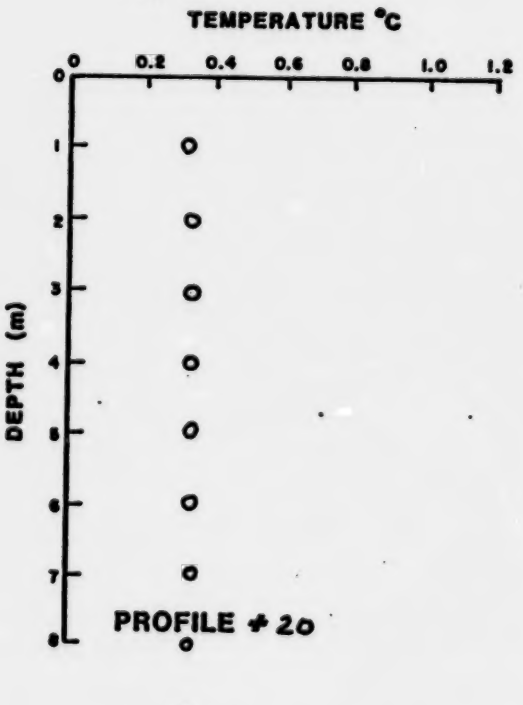
o UP

PORT SLIP: EXPERIMENTAL SLIP (BUBBLING SYSTEM)
DATE : MARCH 24, 1983
TIME :
AIR TEMP. : -11.242



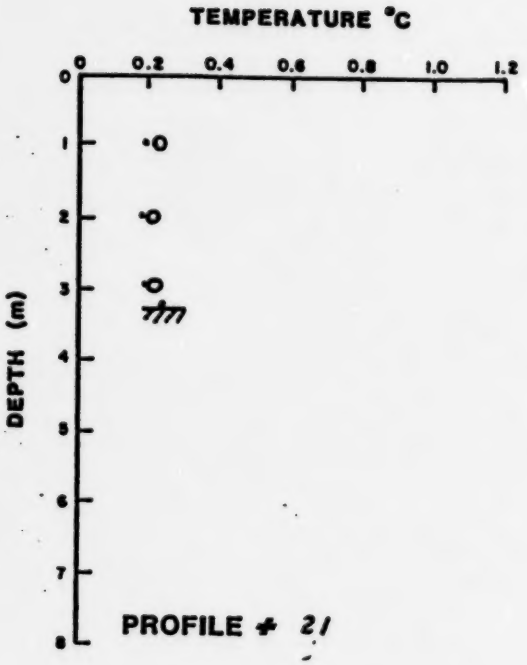


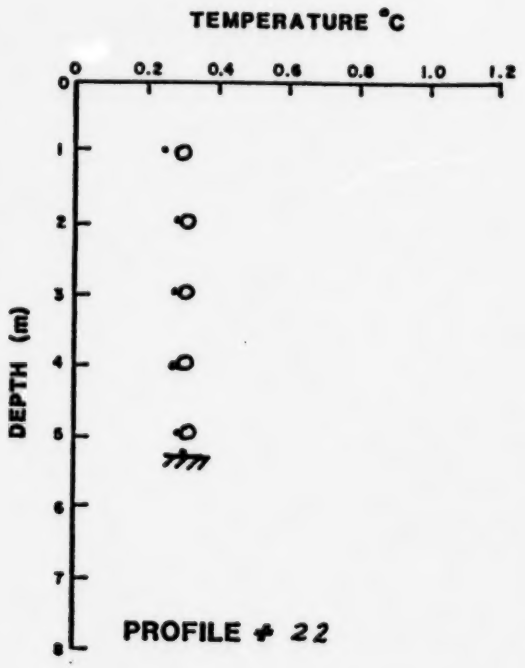


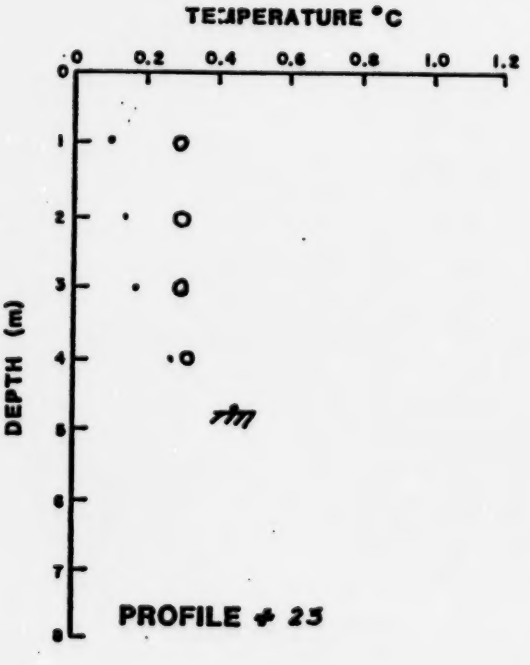


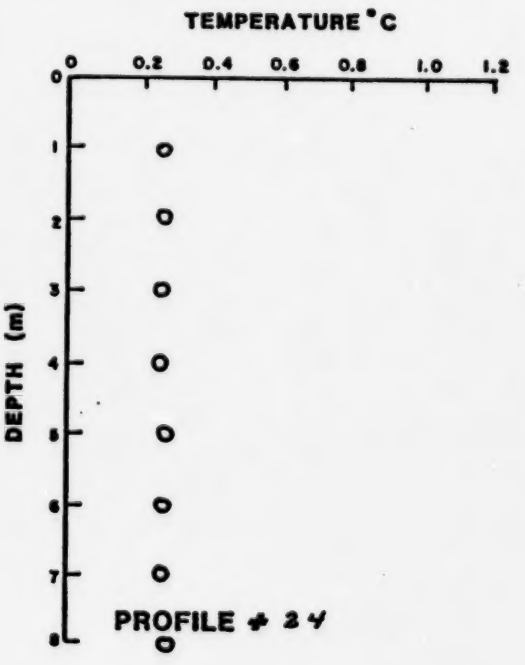
• DOWN
o UP

PORT SLIP: EXPERIMENTAL SLIP
DATE : MARCH 23, 1983
TIME :
AIR TEMP. : -11.422









• DOWN
O UP

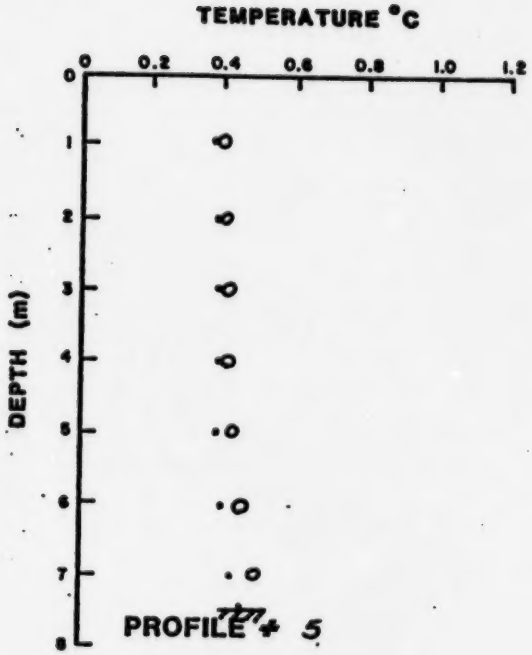
→ 10.5 m : 0.450

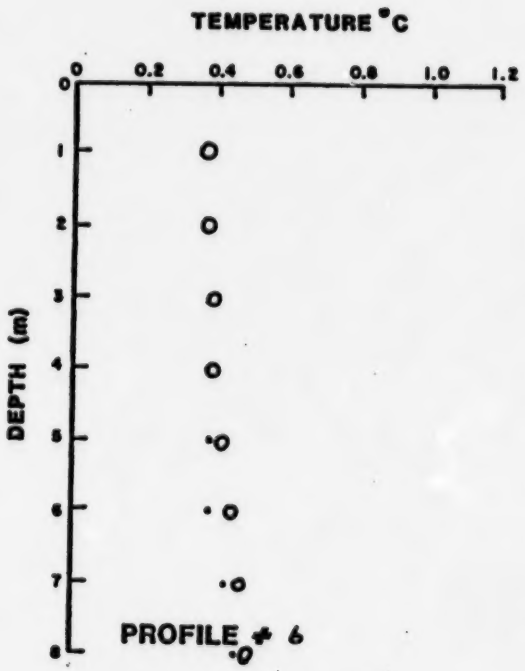
PORT SLIP: POOL 7A (BUBBLING SYSTEM)

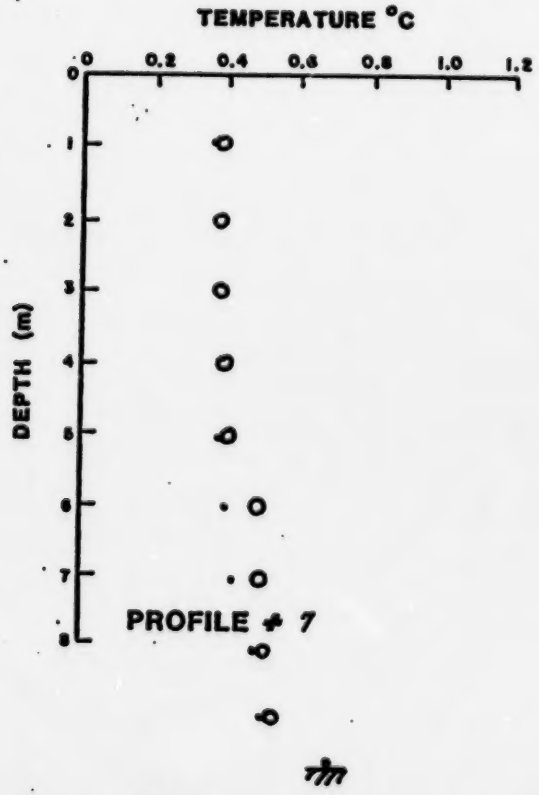
DATE :

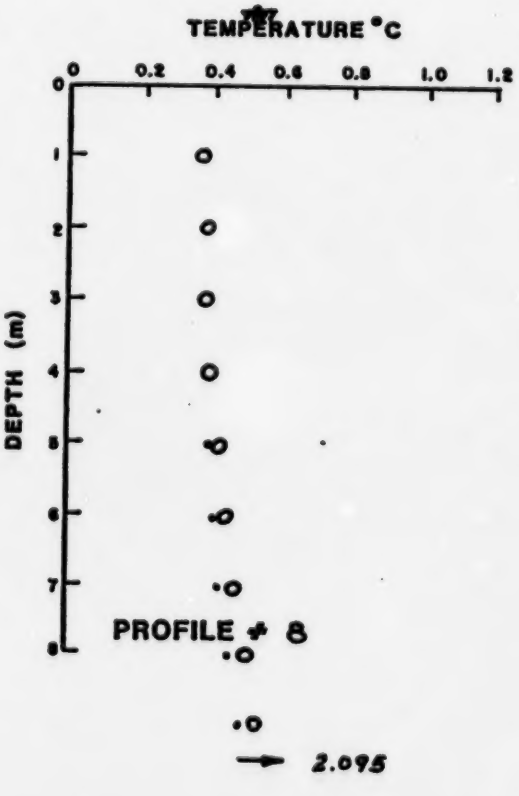
TIME : MARCH 24, 1983

AIR TEMP. : -10.043





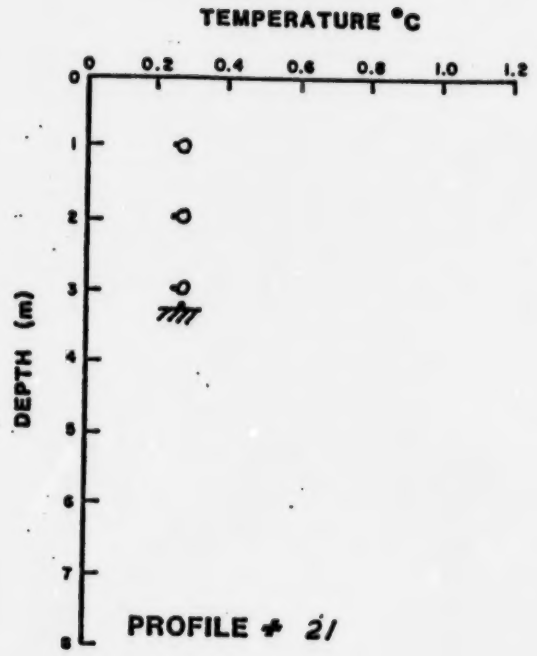




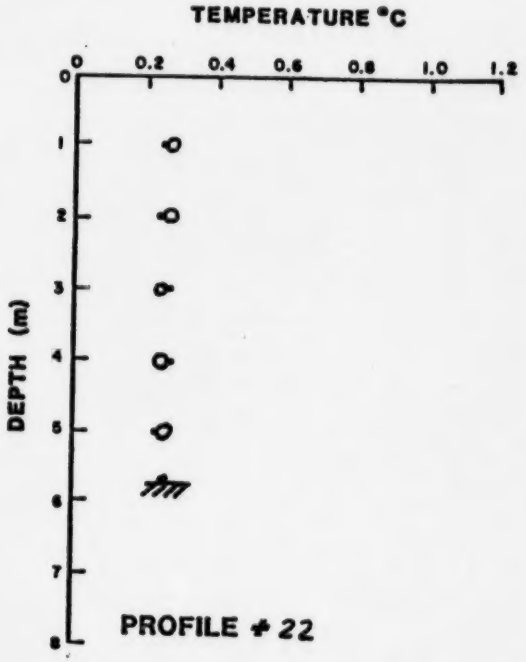
• DOWN

o UP

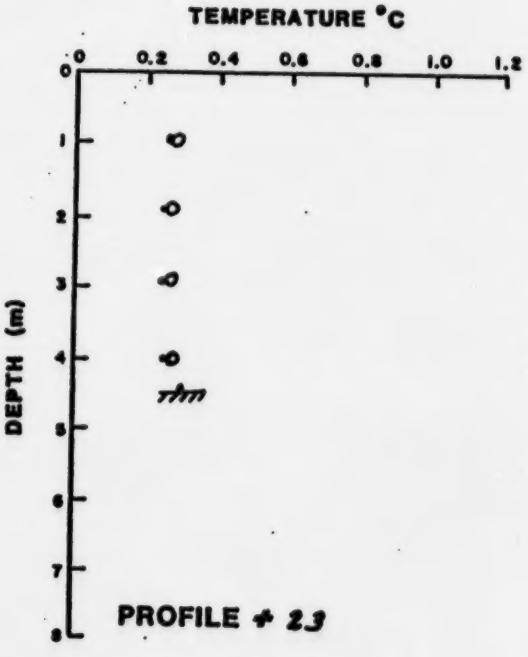
PORT SLIP: EXPERIMENTAL SLIP
DATE : MARCH 22, 1983
TIME : 10:19
AIR TEMP. :



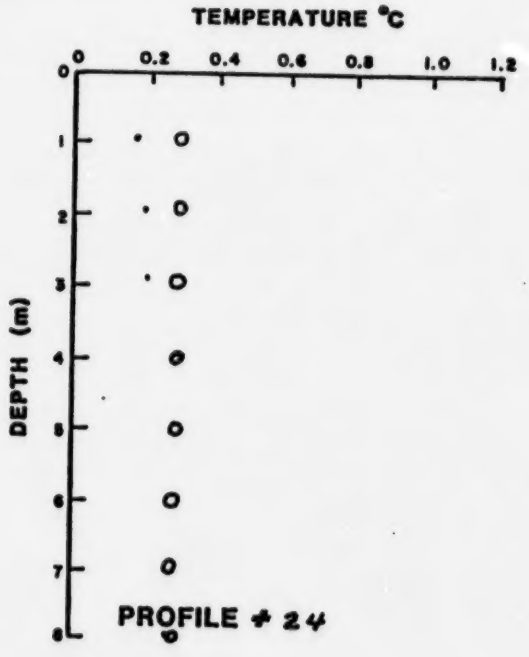
PROFILE # 21



PROFILE # 22



PROFILE # 23



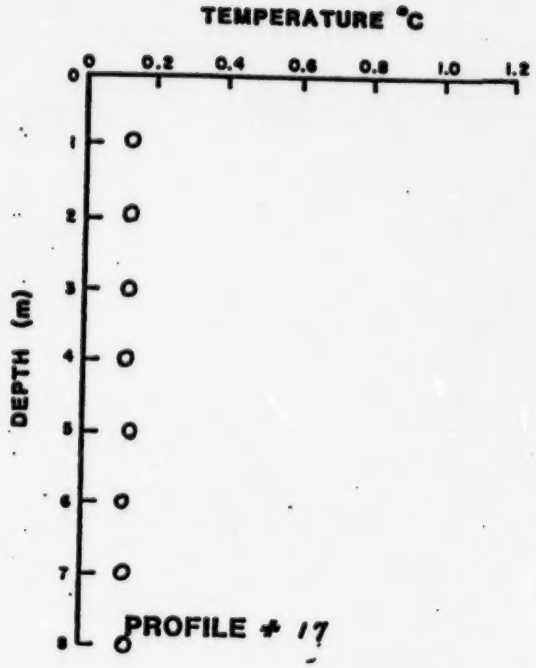
PROFILE # 24

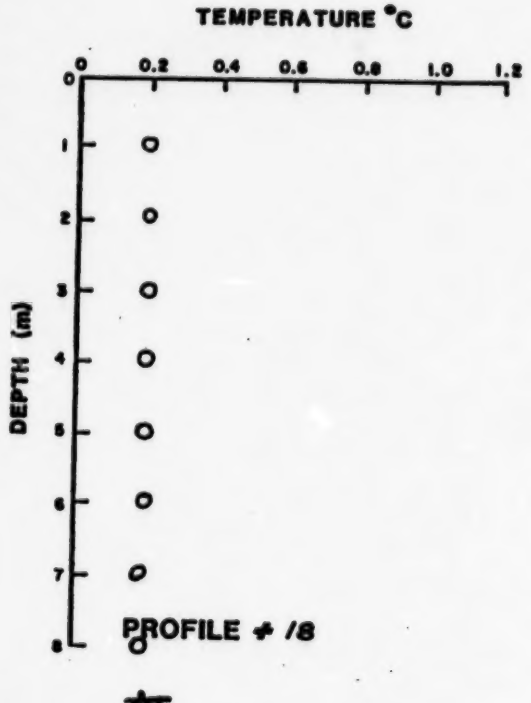
PORT SLIP: EXPERIMENTAL SLIP

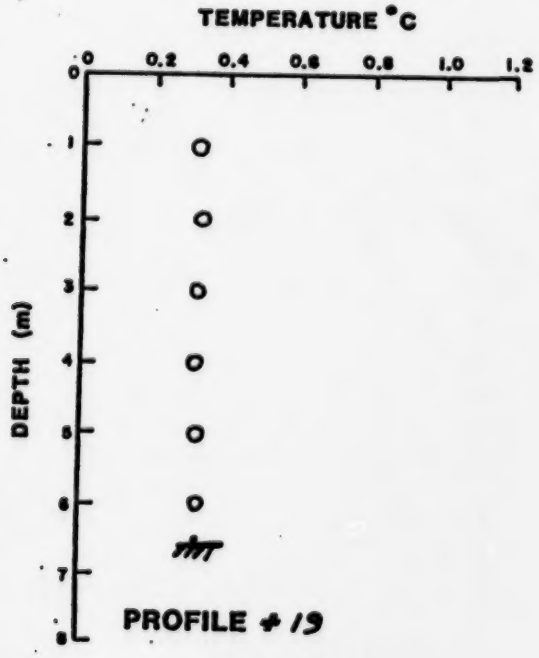
DATE : MARCH 23, 1983

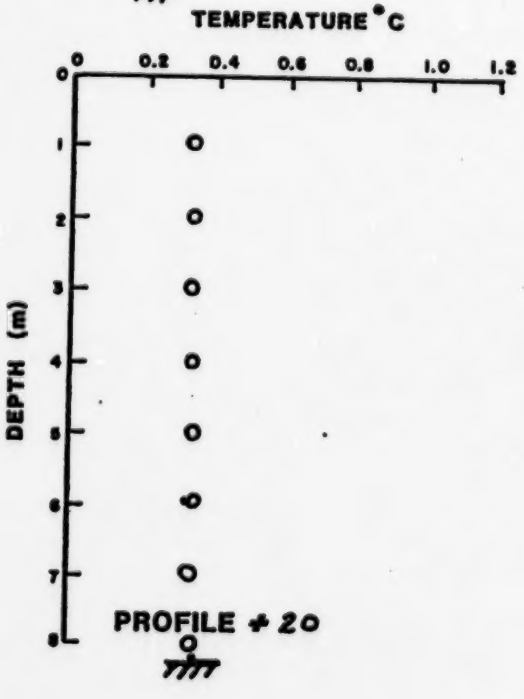
TIME :

AIR TEMP. : - 11.422







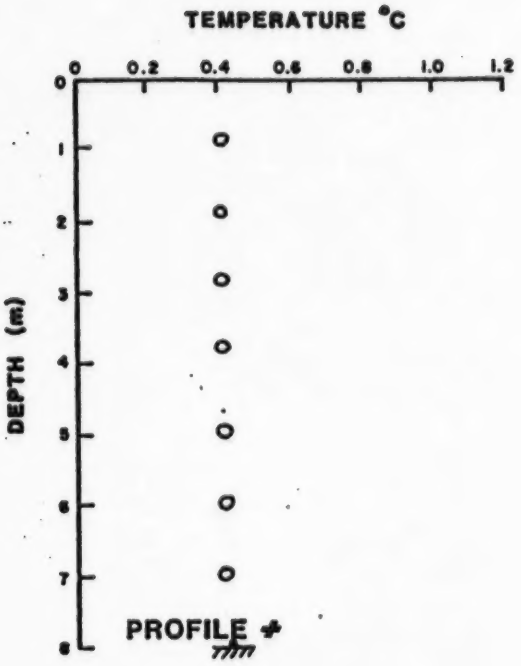


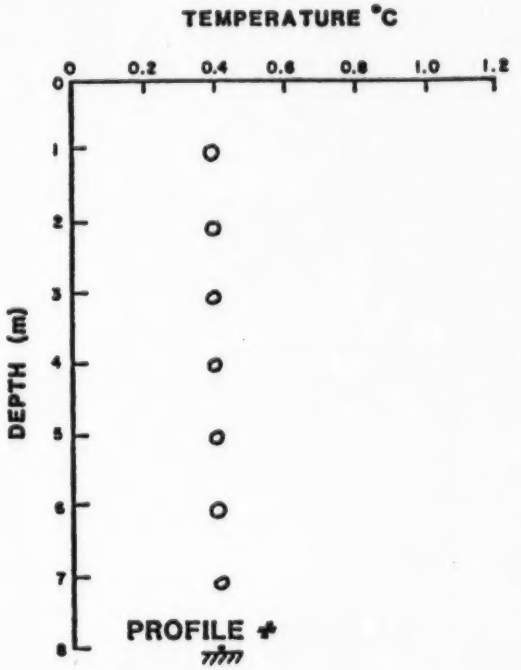
PORT SLIP: POOL 7A

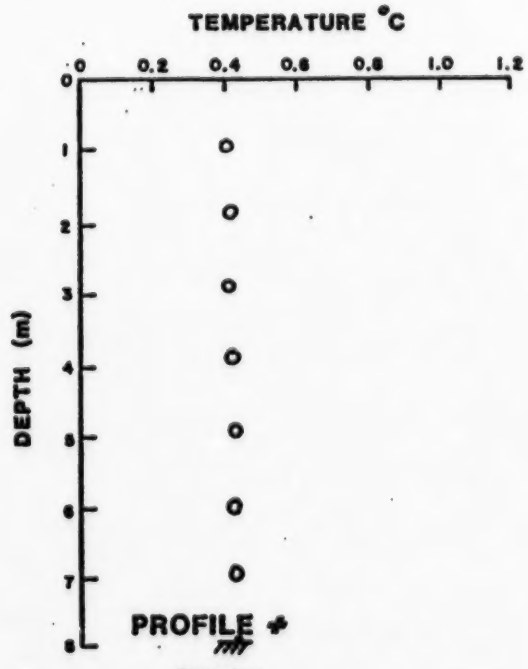
DATE : MARCH 24, 1983

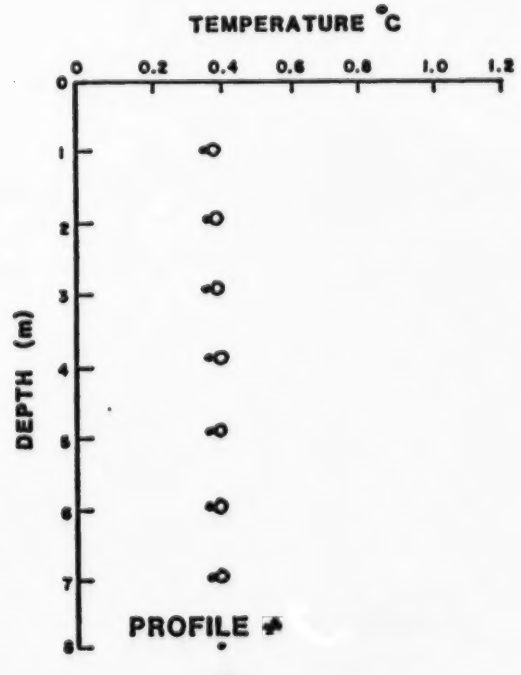
TIME :

AIR TEMP. : -10.043 °C







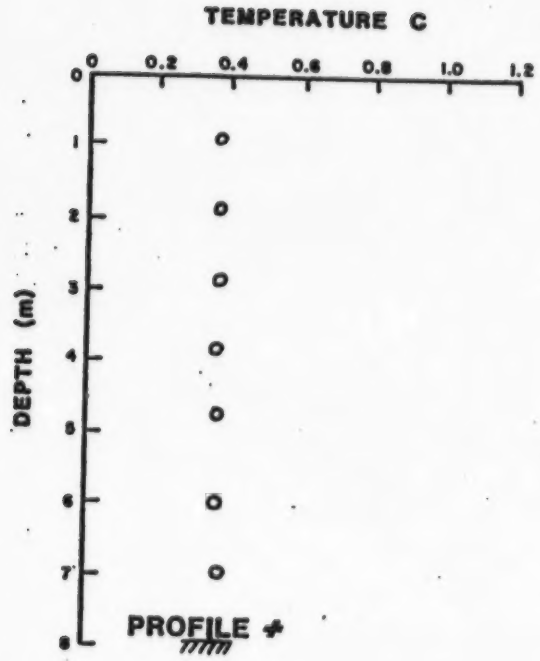


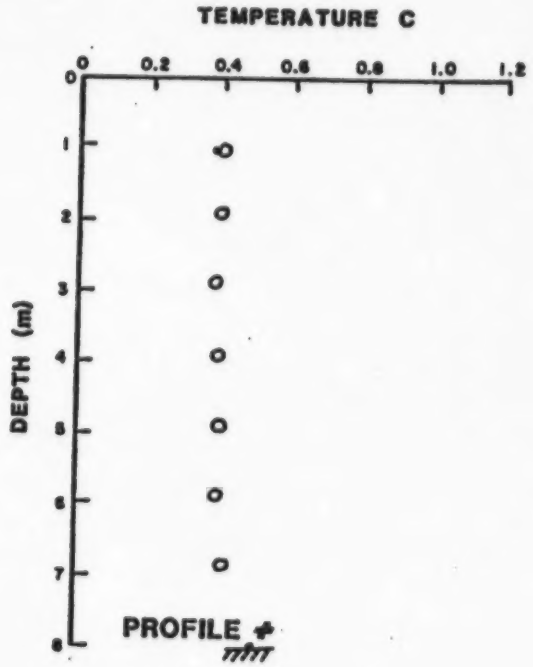
PORT SLIP: POOL 7A

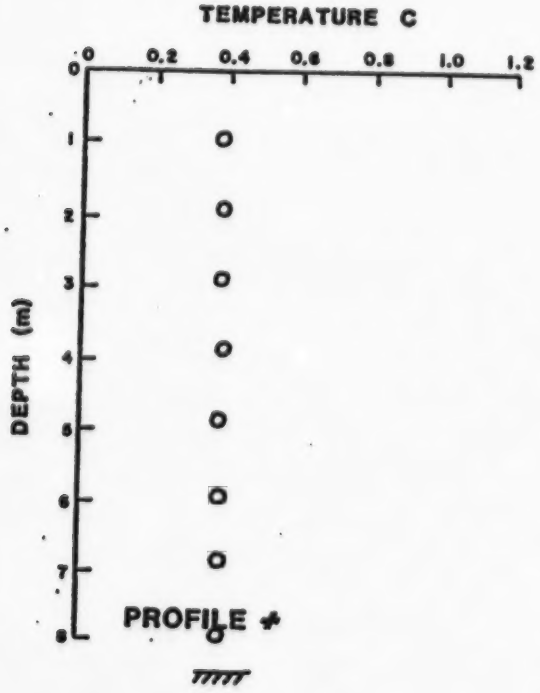
DATE : MARCH 23, 1983

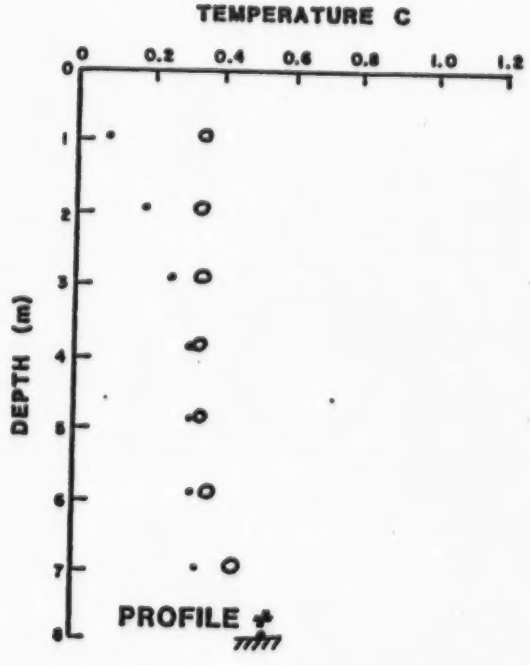
TIME : 11:30

AIR TEMP. : -11.420





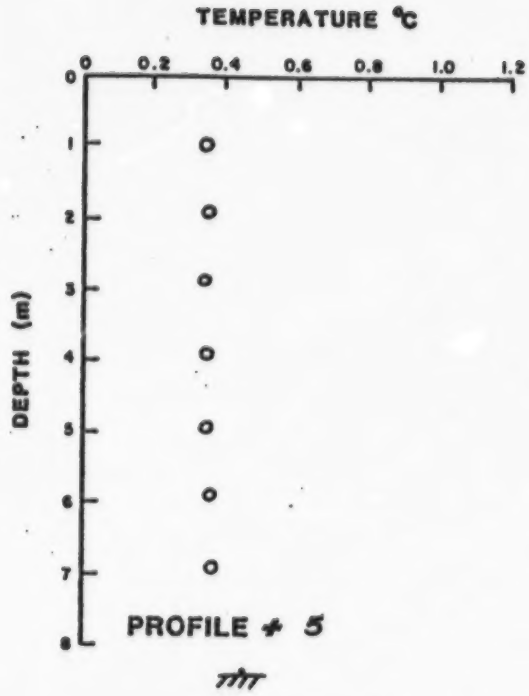


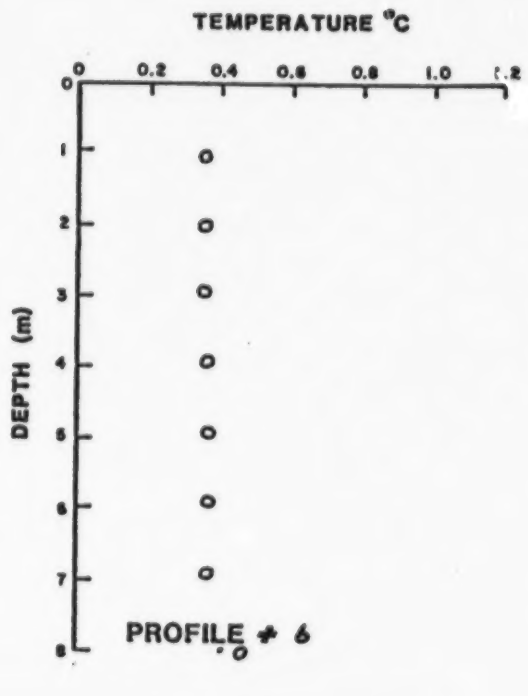


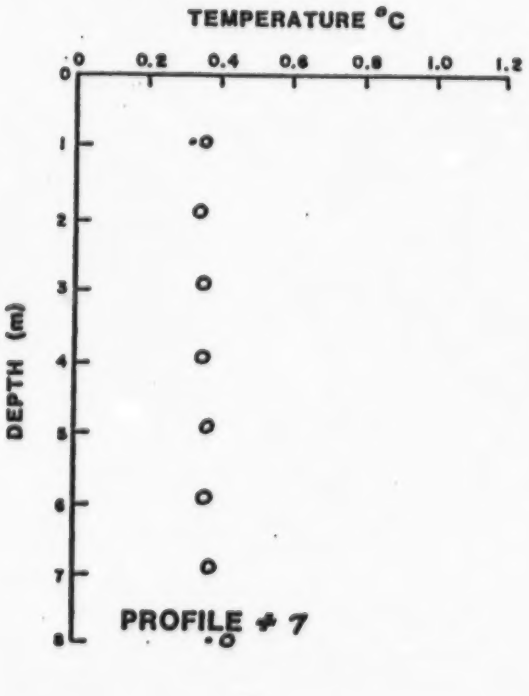
• DOWN

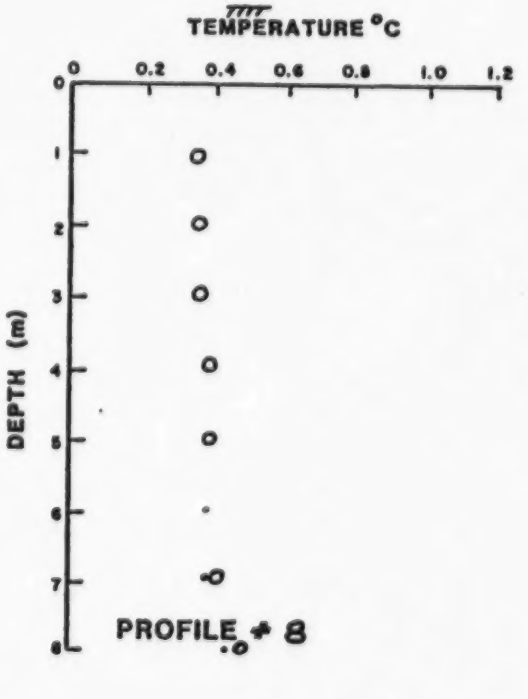
O UP

PORT SLIP: POOL 7A
DATE : MARCH 23, 1983
TIME : 11:30 AM
AIR TEMP. : -10.452 °C









. DOWN
O UP

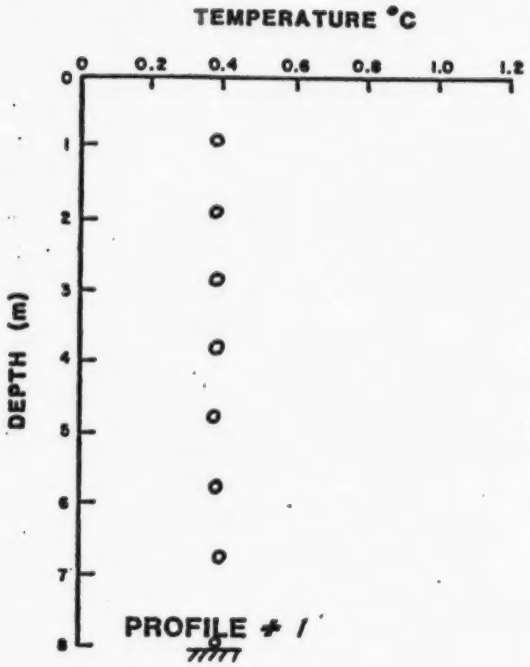
→ 2.240 (IN SOIL)

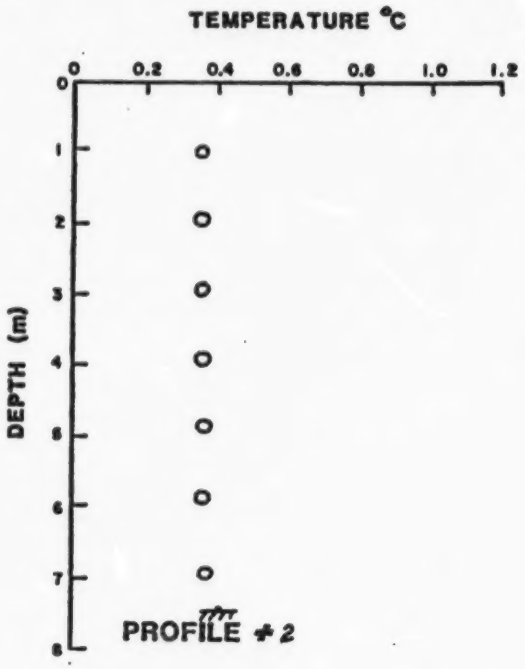
PORT SLIP: POOL 7A

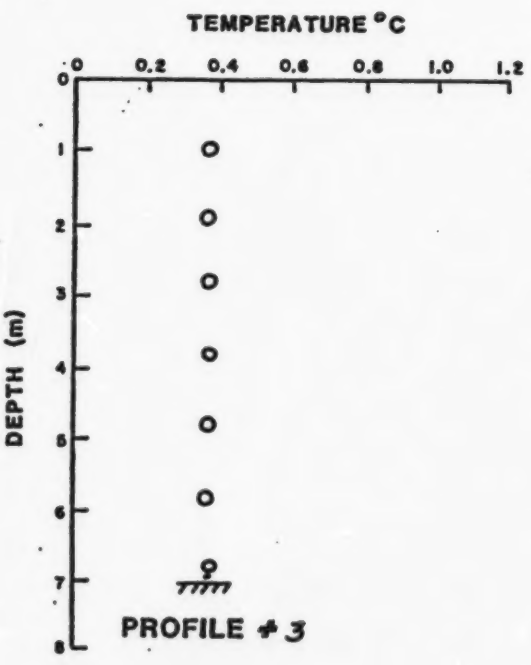
DATE : MARCH 22, 1983

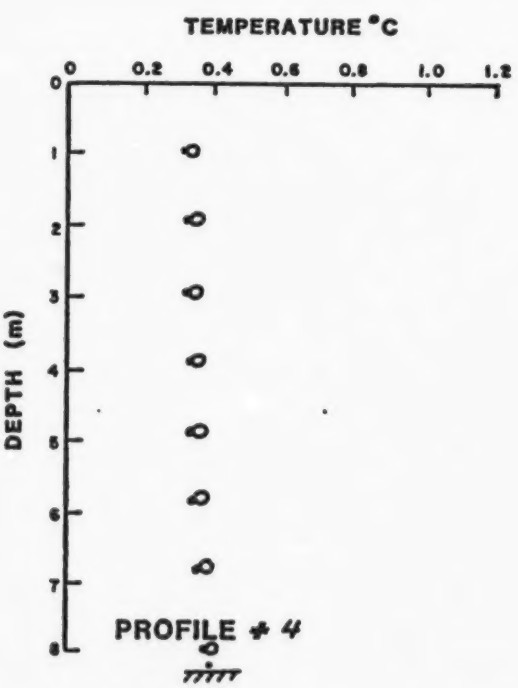
TIME : 11:15

AIR TEMP. : -8.030









. DOWN

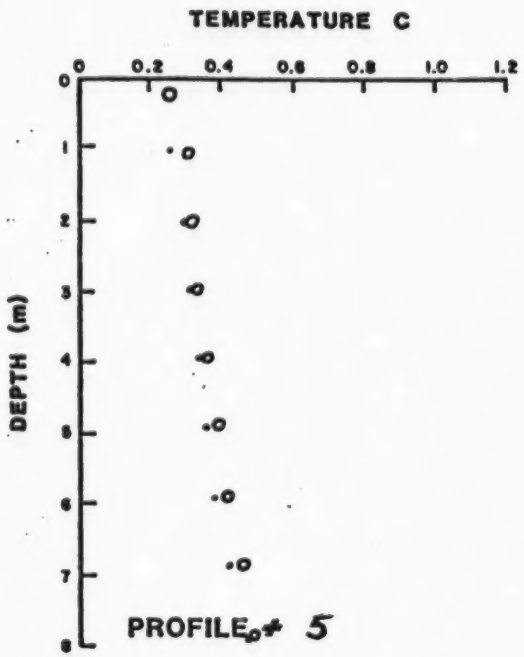
o UP

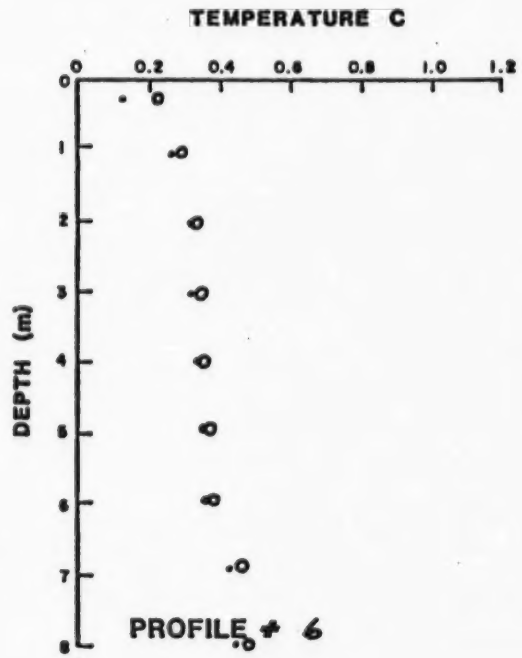
PORT SLIP: POOL 7A

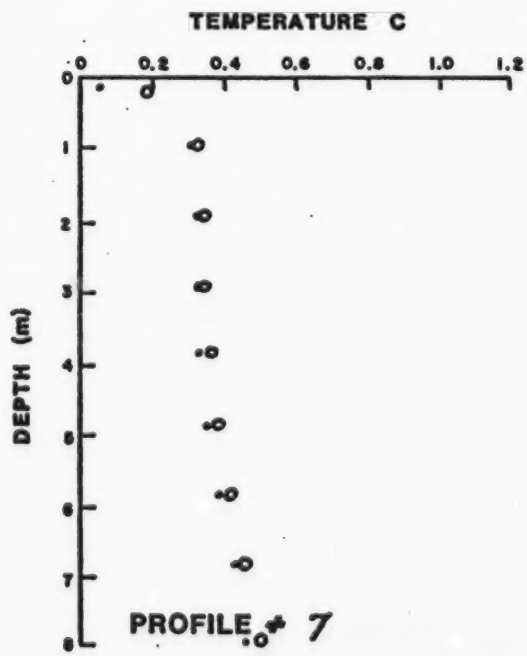
DATE : MARCH 21, 1983

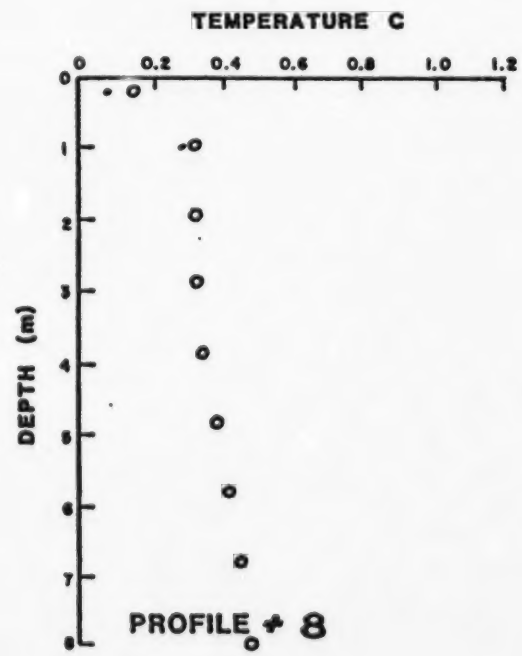
TIME : #5 + #6 10 AM #7 + #8 1.00 - 2:30

AIR TEMP. : -5.79 °C









• DOWN
o UP

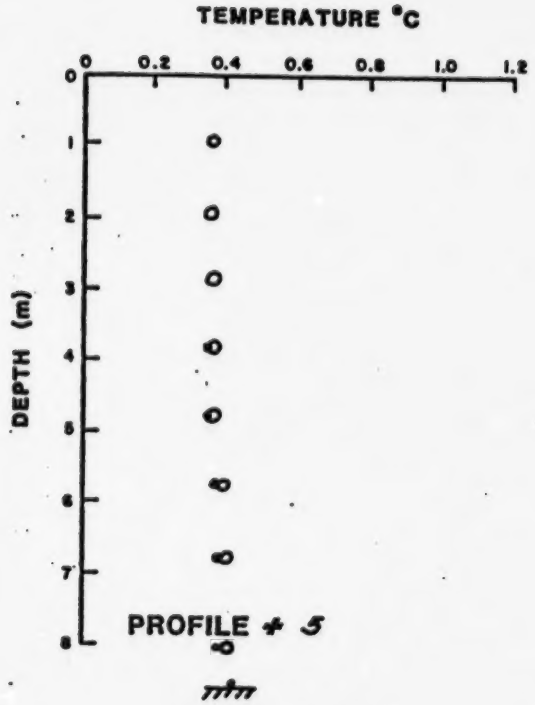
o → 1.771
→ 3.160

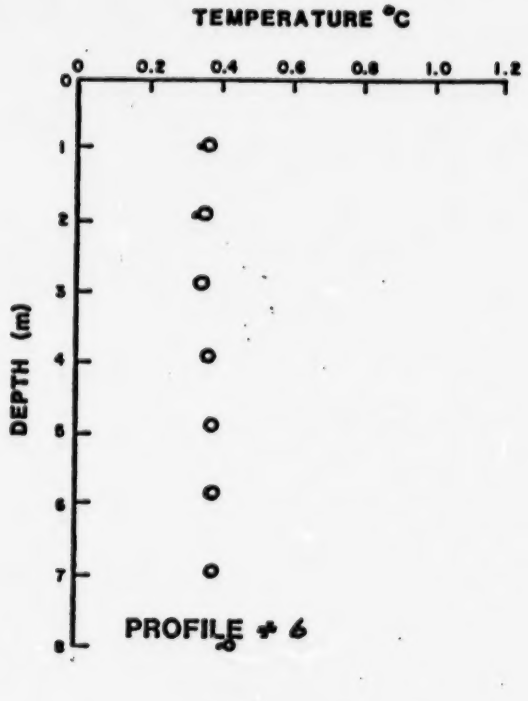
PORT SLIP: POOL 7A

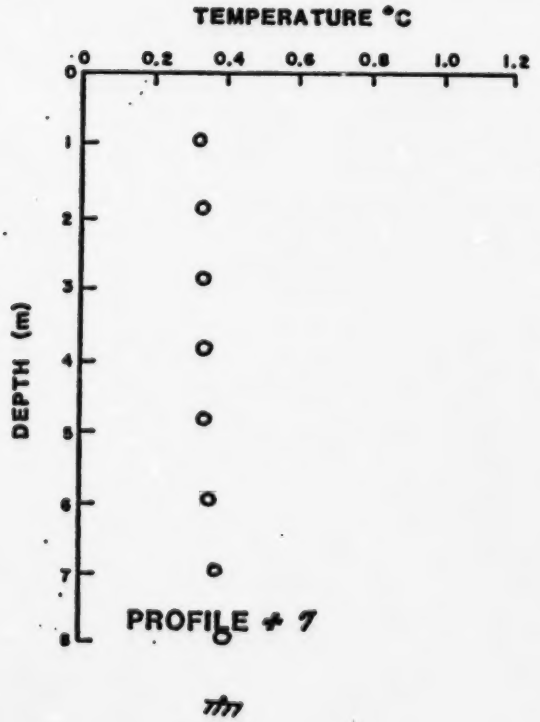
DATE : MARCH 22, 1983

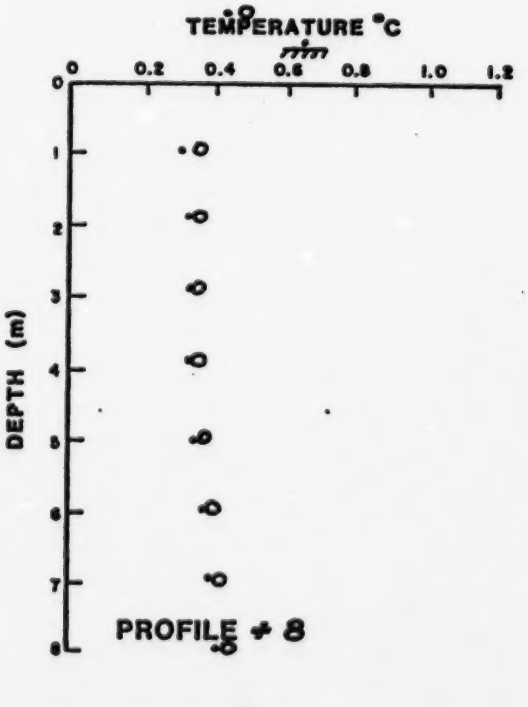
TIME : 12.45

AIR TEMP. : -1.802







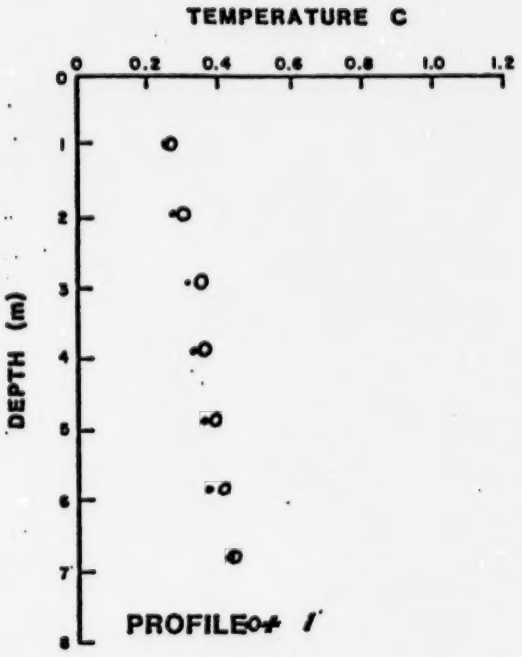


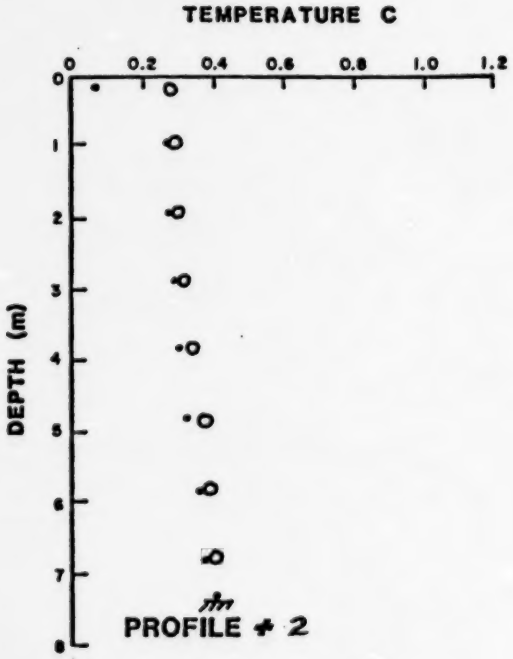
• DOWN

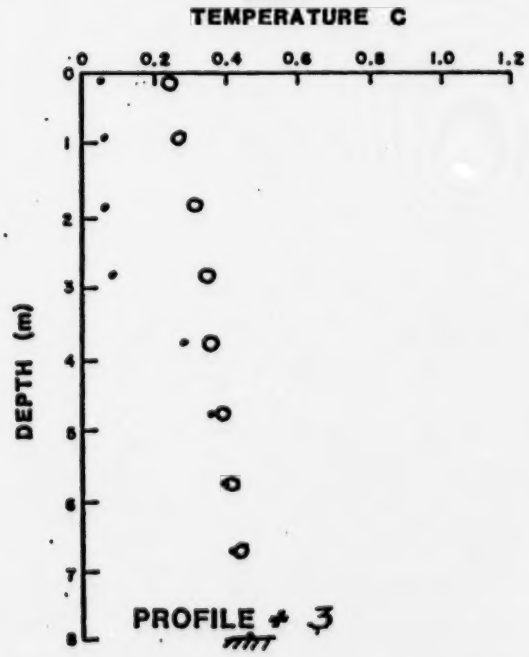
o UP

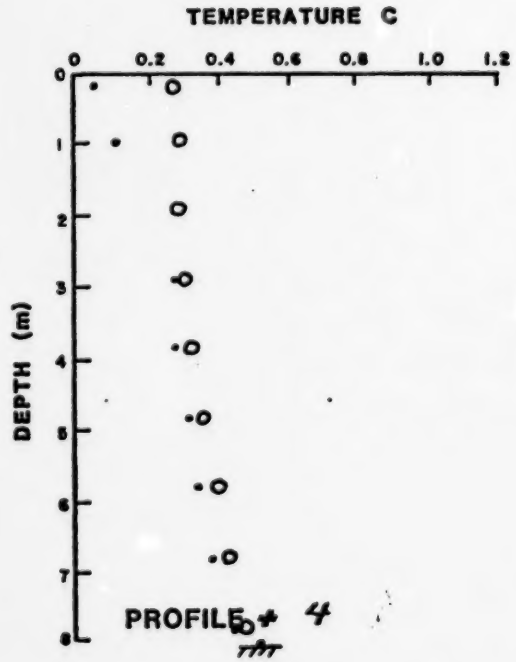
→ 2.238 (IN SOIL)

PORT SLIP: POOL 7A (NO BUBBLER)
DATE : MARCH 21, 1983
TIME : 11AM to 12 PM
AIR TEMP. : -2.56°C

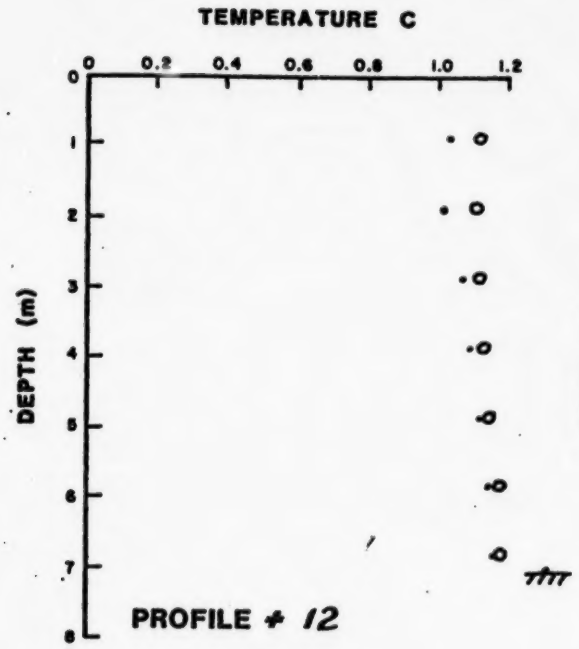


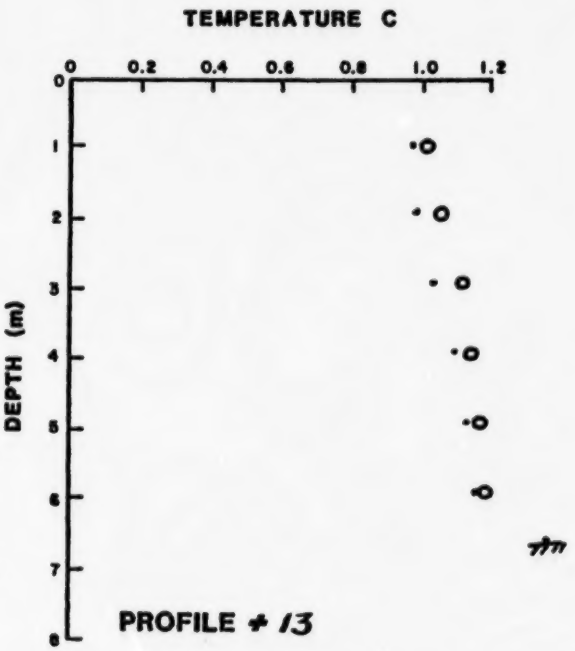


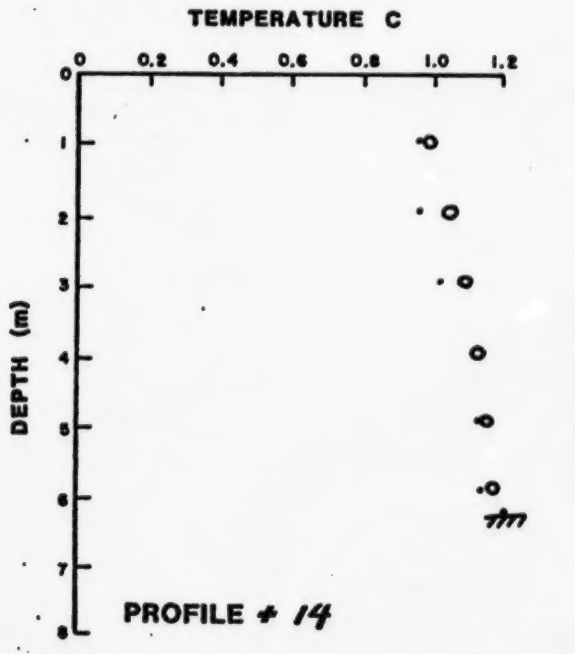


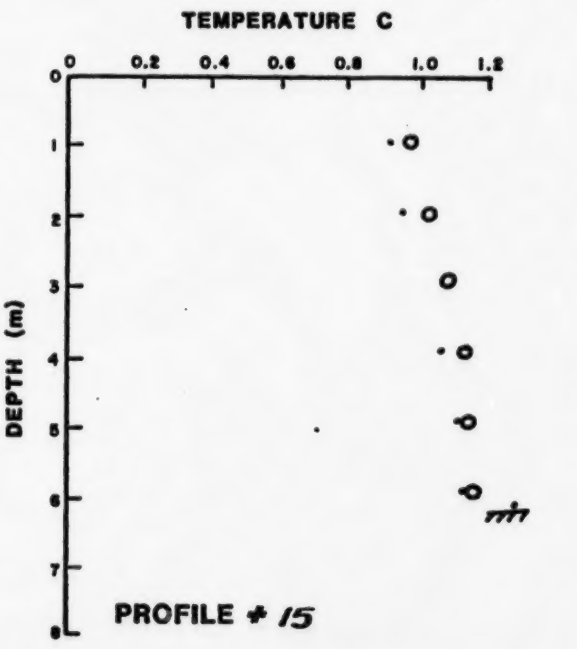


PORT SLIP: CARGILL
DATE : MARCH 23, 1983
TIME :
AIR TEMP. : -6.093









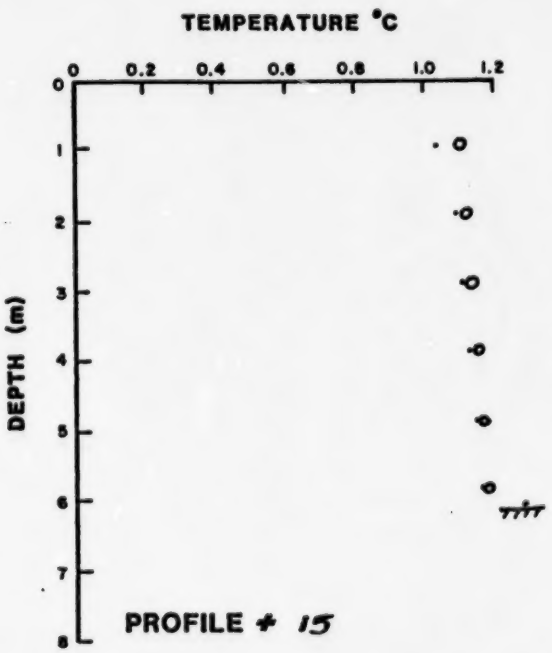
• DOWN
o UP

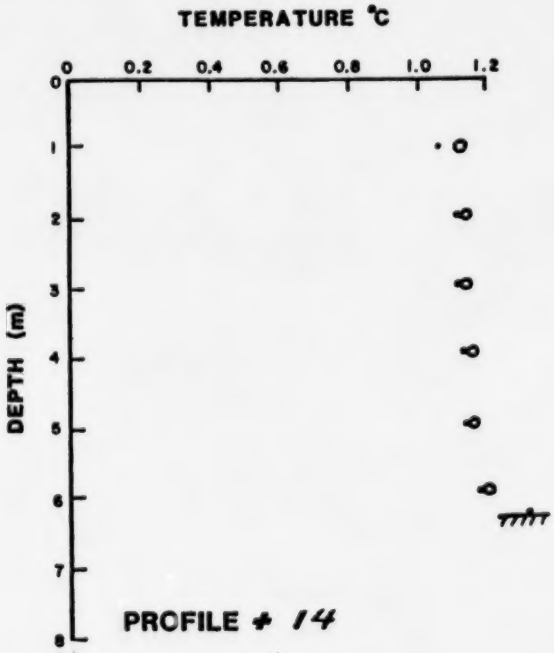
PORT SLIP: CARGILL (NO BUBBLER)

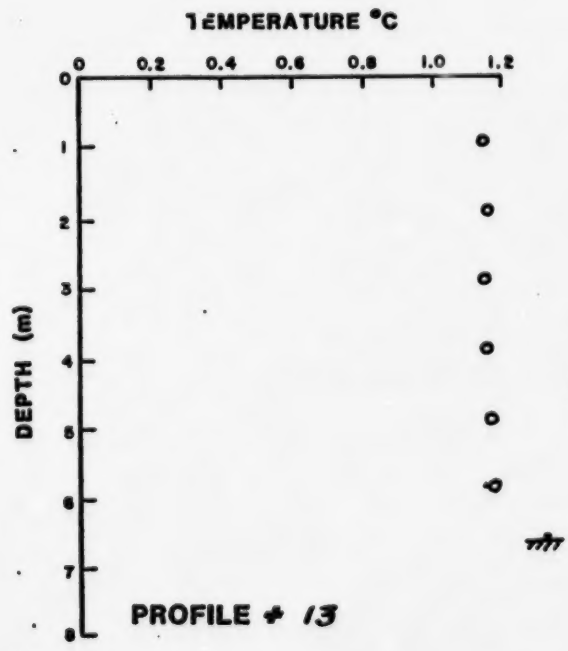
DATE : MARCH 24, 1983

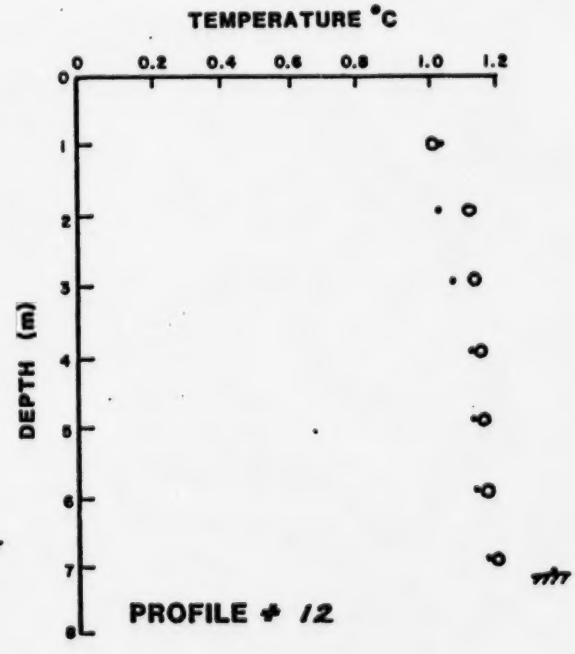
TIME :

AIR TEMP. : -5.825





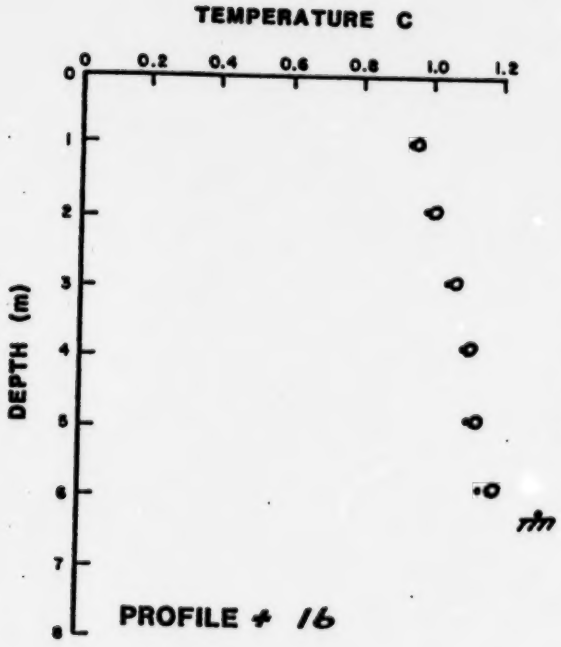


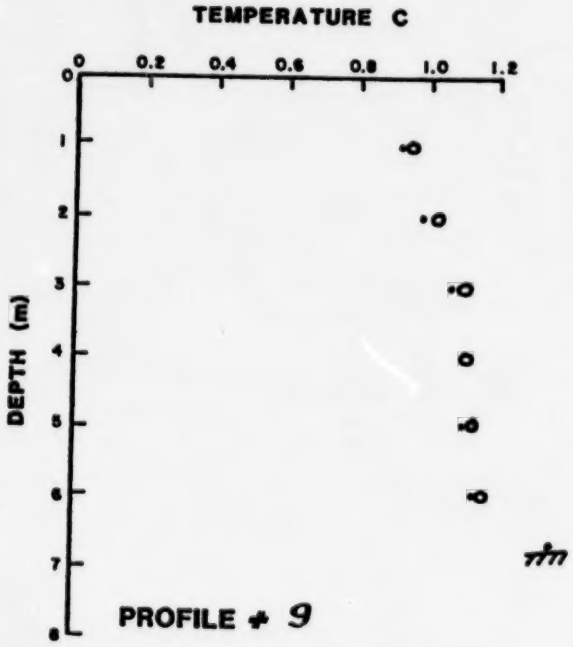


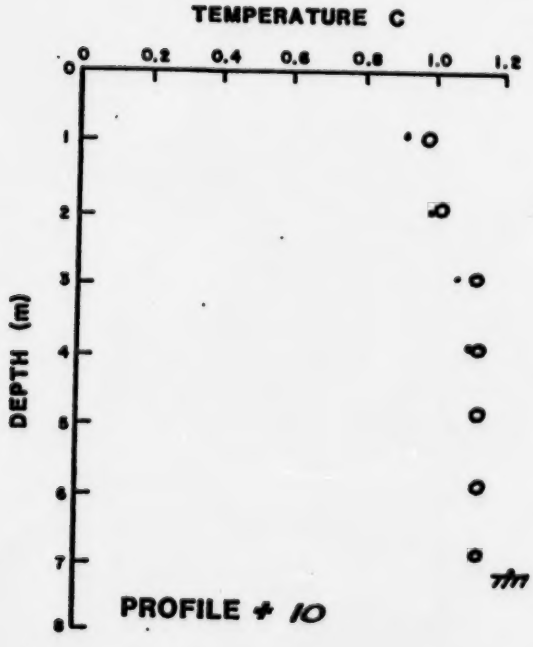
• DOWN

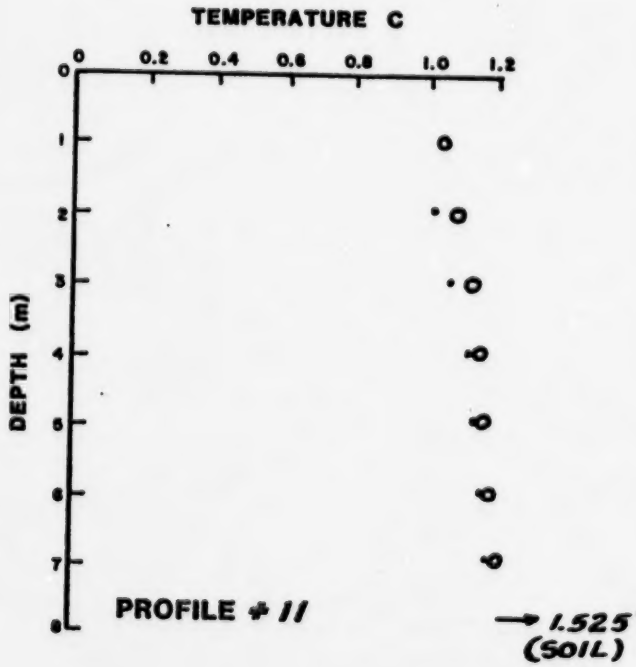
o UP

PORT SLIP: CARGILL (NO BUBBLER)
DATE : MARCH 23, 1983
TIME :
AIR TEMP. : -6.093°C



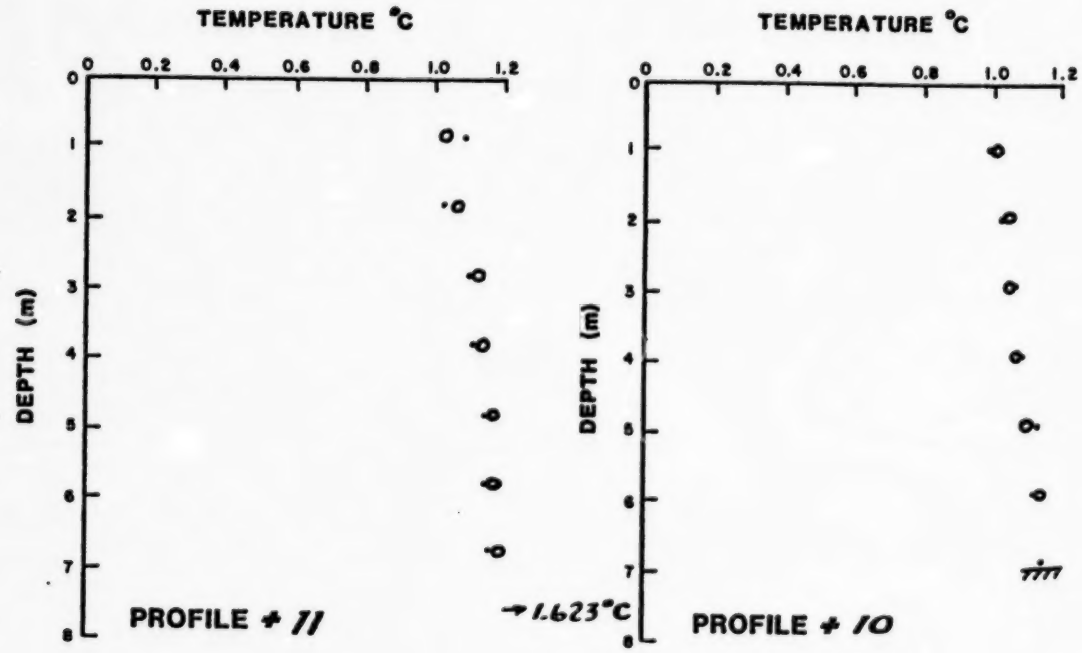


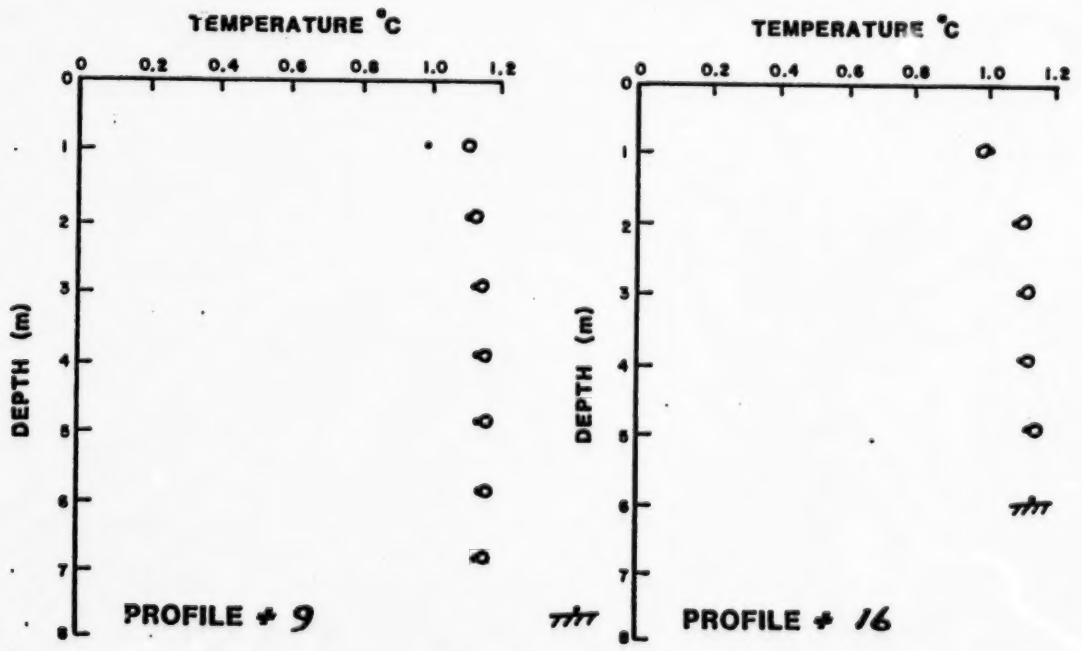




• DOWN
o UP

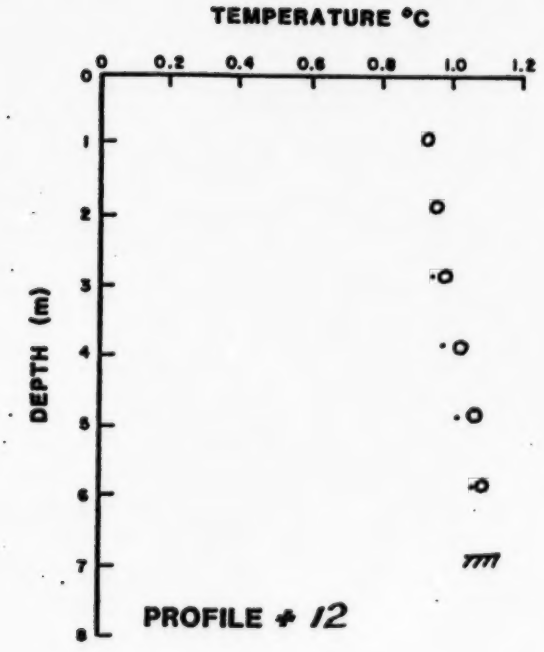
PORT SLIP: CARGILL (NO BUBBLER)
DATE : MARCH 24, 1983
TIME :
AIR TEMP. : -5.825 °C

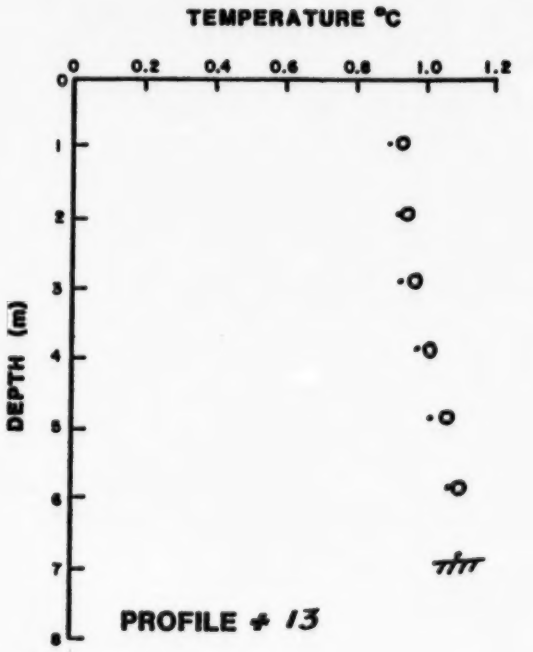


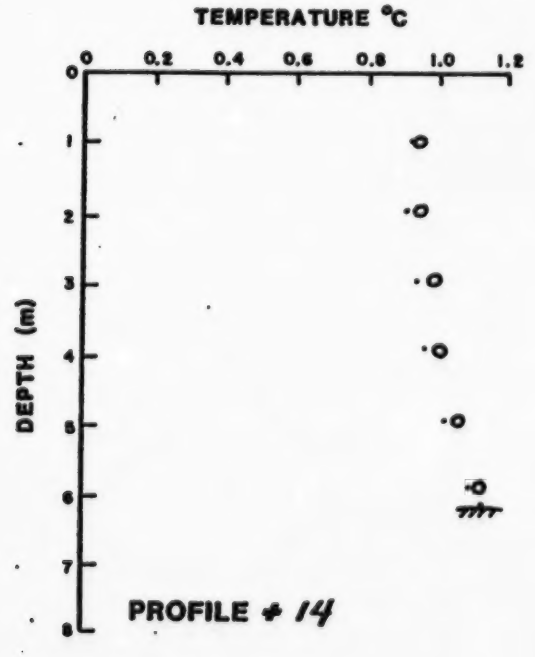


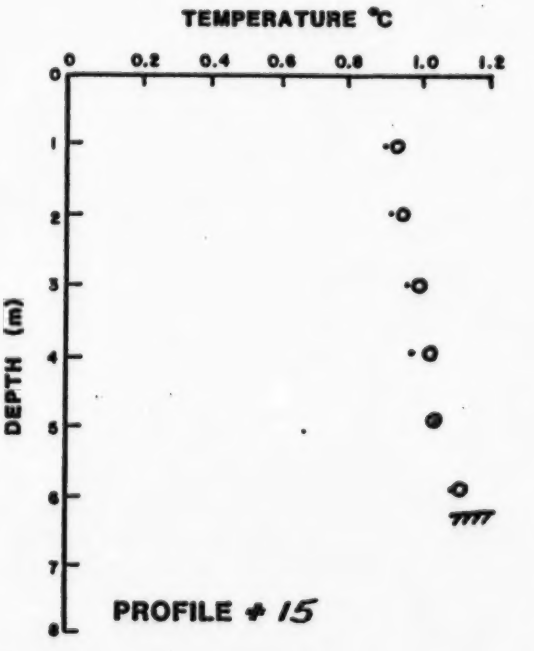
• DOWN
o UP

PORT SLIP: CARGILL (NO BUBBLER)
DATE : MARCH 22, 1983
TIME : 13:40
AIR TEMP. : - 6.5



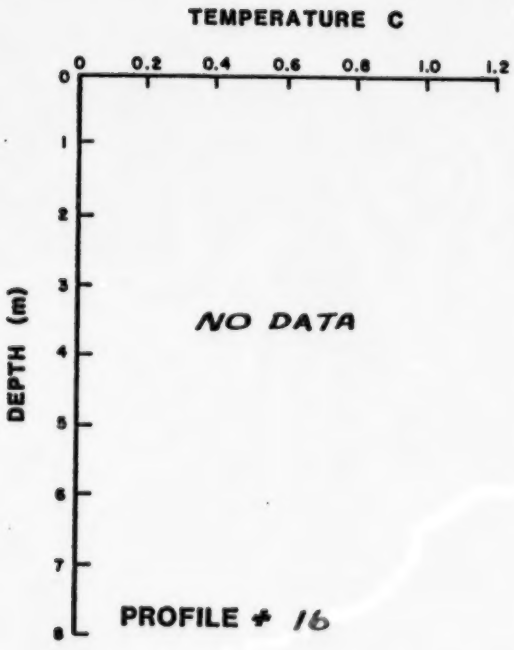


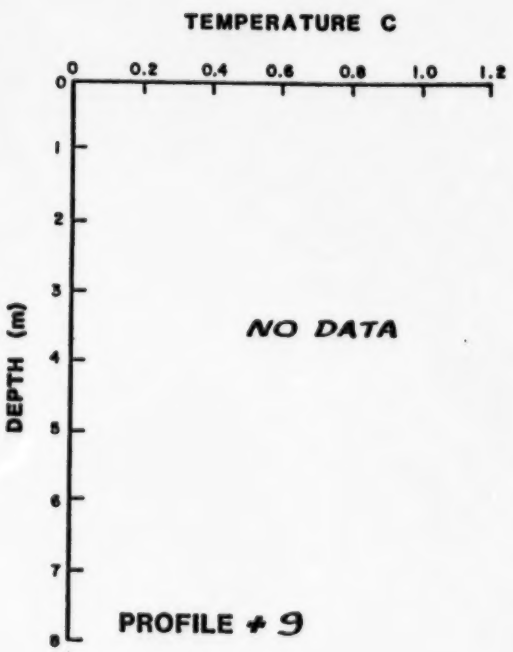


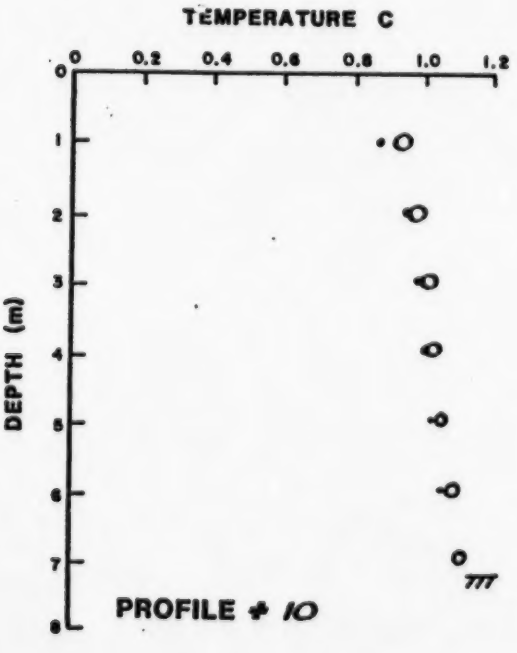


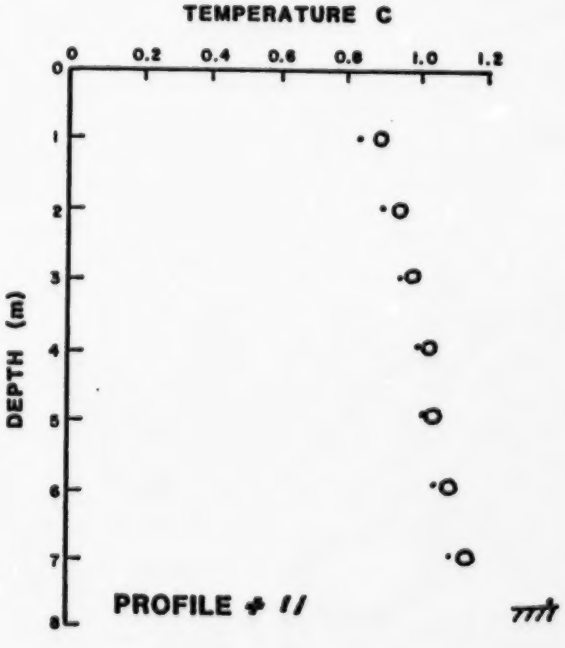
- DOWN
o UP

PORT SLIP: CARGILL (NO BUBBLER)
DATE : MARCH 22, 1983
TIME : 400 PM
AIR TEMP. : -6.8 °C



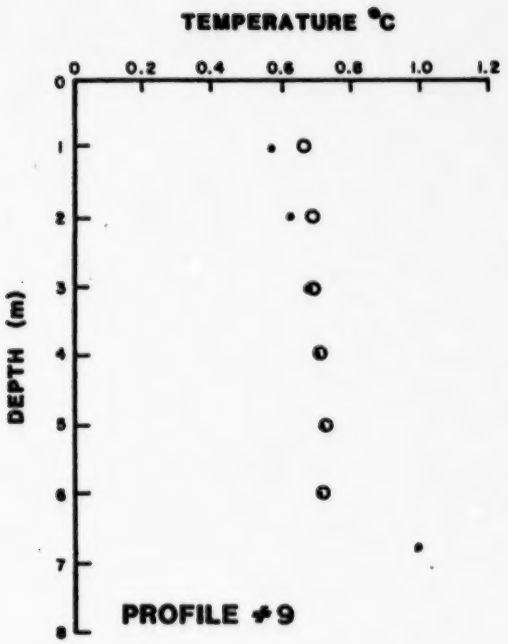


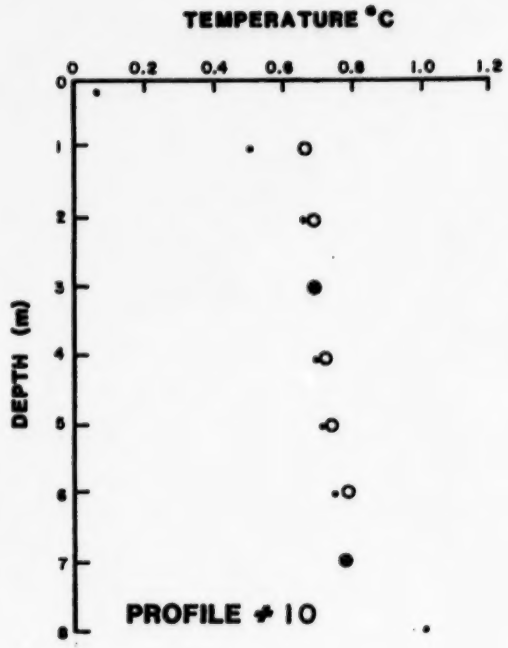


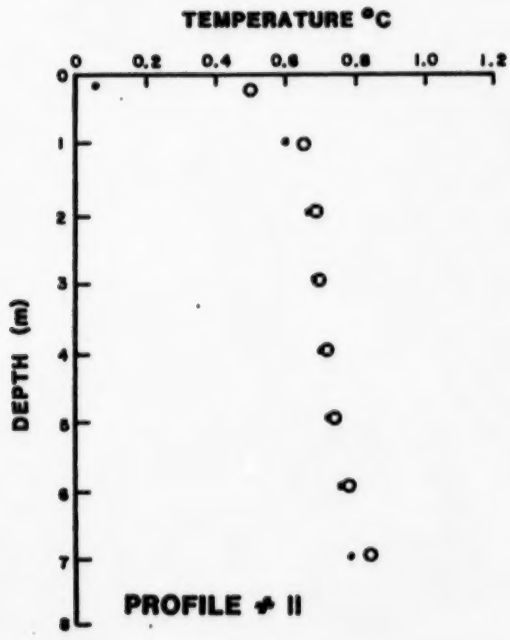


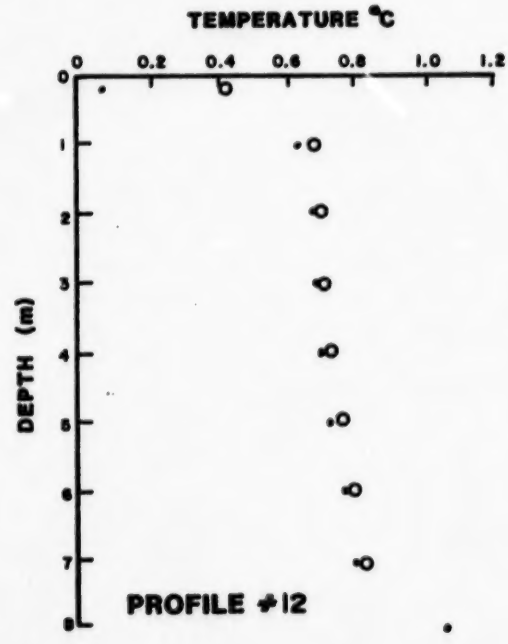
• DOWN
o UP

PORT SLIP: CARGILL
DATE : MARCH 21, 1983
TIME : 4-5 PM
AIR TEMP. : -5.8°C



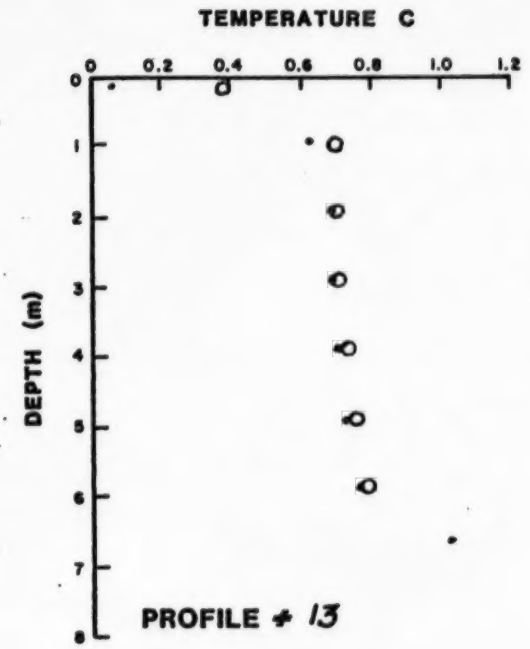


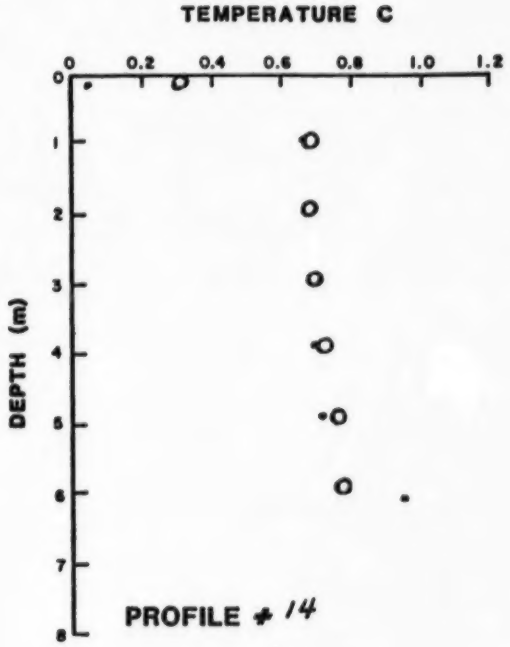


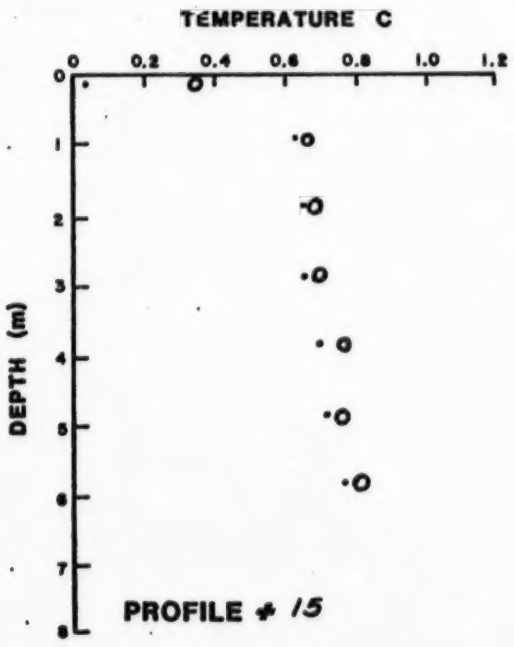


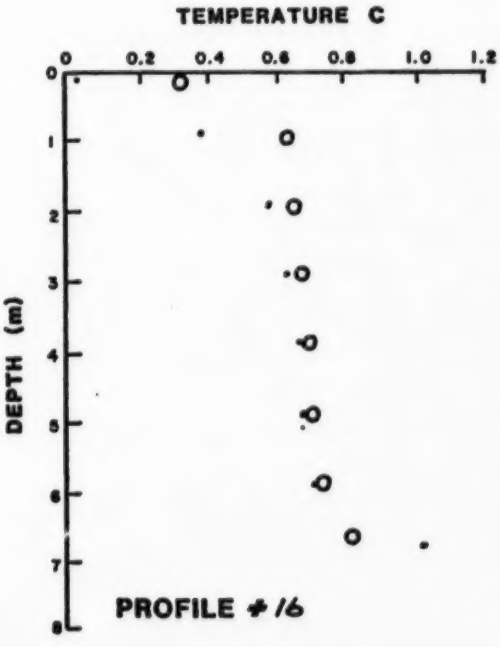
• DOWN
o UP

PORT SLIP: CARGILL
DATE : MARCH 21, 1983
TIME : 4-5 PM
AIR TEMP. : - 5.8 °C









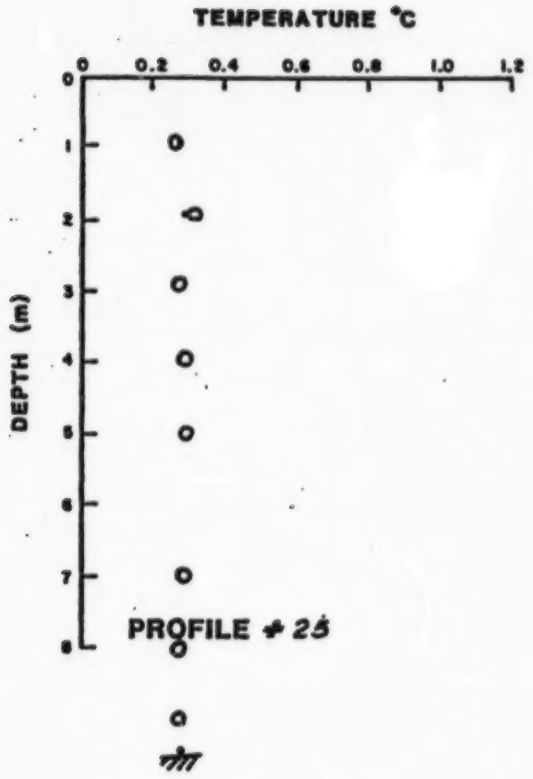
• DOWN
O UP

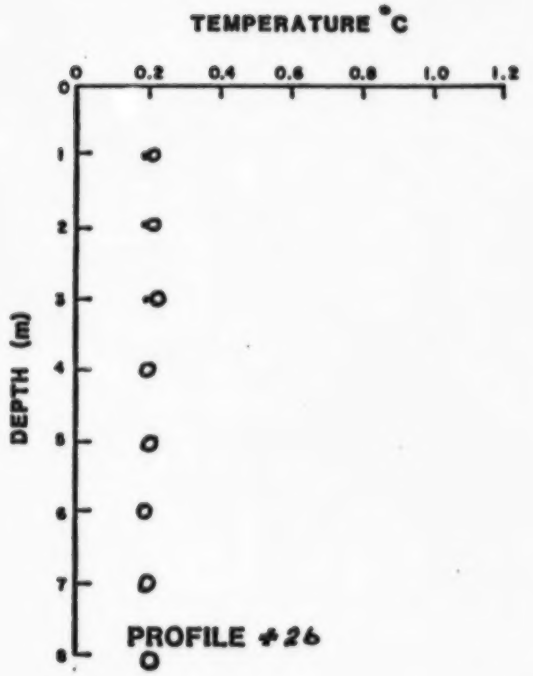
PORT SLIP: EXPERIMENTAL SLIP

DATE : MARCH 22, 1983

TIME : 10:25

AIR TEMP. :



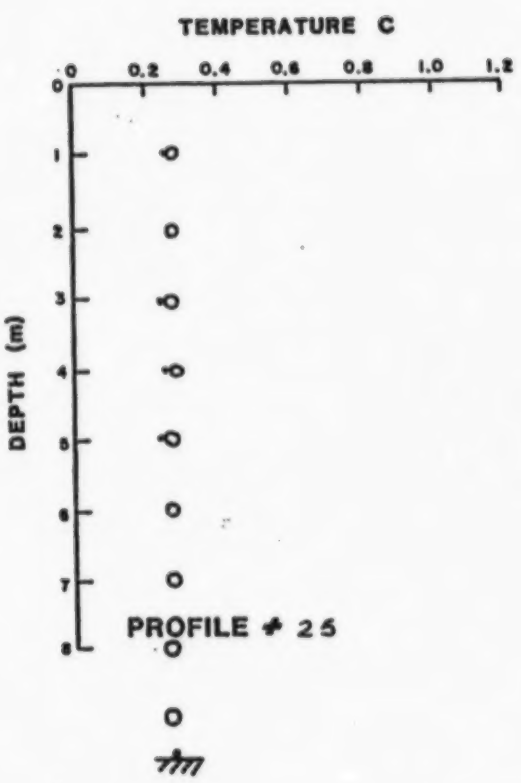


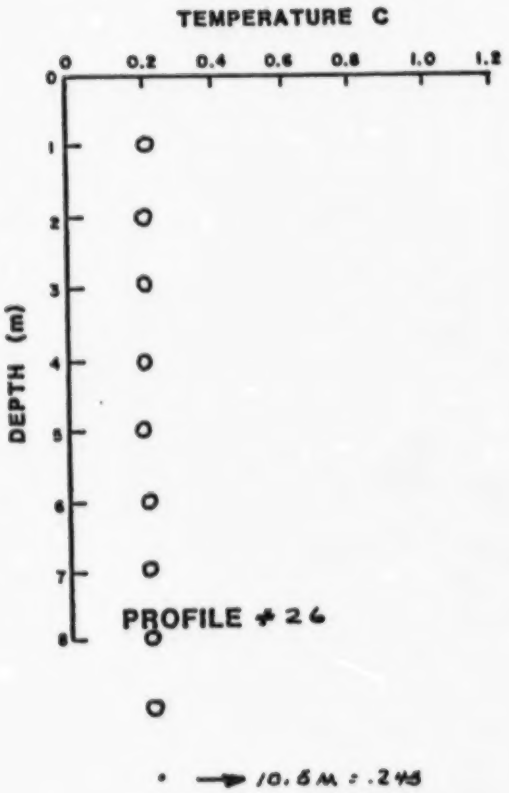
PORT SLIP: EXPERIMENTAL SLIP

DATE : MARCH 23, 1983

TIME :

AIR TEMP. :





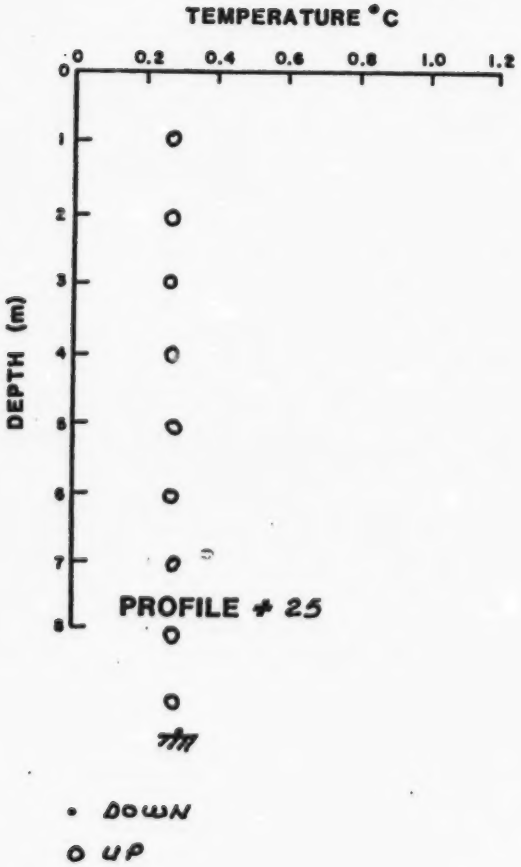
• → 10.6M = .24S

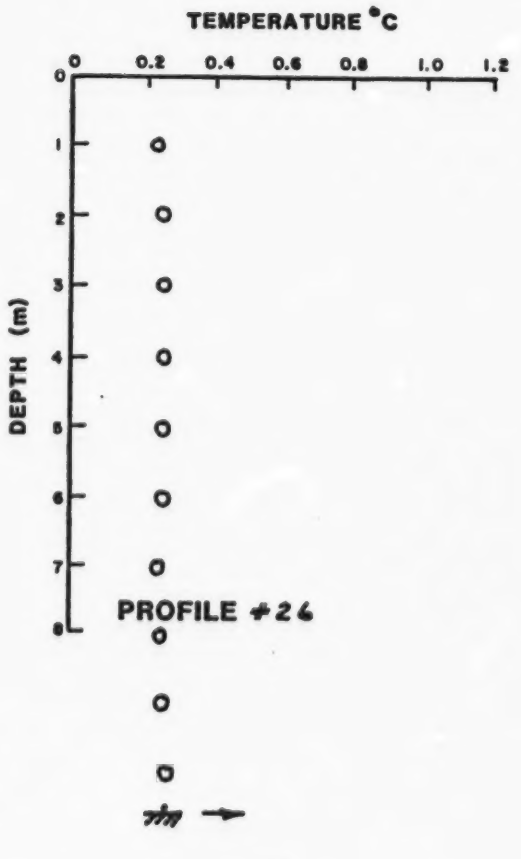
PORT SLIP: EXPERIMENTAL SLIP

DATE : MARCH 24, 1983

TIME :

AIR TEMP. : -11.242





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